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Quarterly Report

ENERGY PROGRAMS

at The Johns Hopkins University Applied Physics Laboratory

OCTOBER—DECEMBER 1976

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY

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This volume contains a record of the activities of the Applied Physics Laboratory in the development of energy sources and energy storage methods. The larger number of articles describe APL activities that assist the Planning Office of the Division of Geothermal Energy (DGE) of ERDA. Efforts in this field are concentrated on resource assessment and utilization in DGE Region 5 (the states east of the Rocky Mountains, excluding Texas and Louisiana). The other sections describe three efforts: design of a Community Annual Storage Energy System, developmental work on polycrystalline silicon solar cells, and design and experimental work on a system to use ocean thermal energy.

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Quarterly Report

ENERGY PROGRAMS

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OCTOBER–DECEMBER 1976

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY
Johns Hopkins Road ○ Laurel, Maryland ○ 20810

PREFACE

The Johns Hopkins University Applied Physics Laboratory, under contracts with the U.S. Energy Research and Development Administration (ERDA) and with the U.S. Maritime Administration, Department of Commerce, is engaged in the development of energy resources and energy storage methods. This Quarterly Report summarizes the work completed on the various tasks as of 31 December 1976.

The first, larger section of this volume describes APL activities that assist the Planning Office of the Division of Geothermal Energy (DGE) of ERDA. Efforts in this field are concentrated on resource assessment and utilization in DGE Region 5 (the states east of the Rocky Mountains, excluding Texas and Louisiana).

The other sections describe three efforts: design of a Community Annual Storage Energy System, developmental work on polycrystalline silicon solar cells, and design and experimental work on a system to use ocean thermal energy.

Future volumes will report the results of these and other energy-related projects in which APL is currently engaged.

TABLE OF CONTENTS

COMMENTS ON LIMITED TASKS

This section of the EQR discusses tasks that are either in the formative or terminal stage, or with which APL has assisted some other section of the Geothermal Division of ERDA.

MEETINGS AND TRIPS

Visit to Midwest Research Institute

On 19 December 1976, Laboratory personnel visited the Midwest Research Institute (MRI) in Kansas City, MO. MRI is a subcontractor to Futures Group, Inc. and is engaged in work on geothermal energy applied to crop drying and processing. Jerry Bradley of MRI accompanied APL personnel to a Workshop on Geothermal Energy in Kansas held at the Kansas State Geologic Survey on 20 December 1976.

Visit to Information Systems Programs Office, University of Oklahoma

APL personnel visited the Office on 2 December 1976 to discuss their data storage and retrieval software systems for petroleum and mineral resources. Jerlene Bright is the Director of the Office, which has the following programs in process or operational:

1. General Information Processing System (GIPSY) is the software for systems that have a large data base (Ref. 1).
2. Petroleum Data System is a data file on more than 700 000 oil and gas wells in Oklahoma. It is arranged by district, oil- or gas-field name, pool name, location, size, cumulative and average production, geological occurrence of entrapment, water and oil chemistry, and engineering data. The oil and water chemistry data are being provided by Gene Collins of the ERDA Laboratory, Bartlesville, OK (Ref. 2). Reference 3 is the user's manual for the petroleum data system. The system is sponsored by the U.S. Geological Survey (USGS), Reston, VA, under Allen Clark. The 700 000 logs of individual wells were purchased from Petroleum Information Corp., Denver, CO. Additional information has been made available under the Freedom of Information Act. Since it is proprietary information, the detailed data file is not open; only aggregated data are available. The system is scheduled to be completed in approximately seven years.
3. The North American Oil and Gas Data Bank and Map Project at Oklahoma State University maintains geothermal gradient state maps produced by the American Association of Petroleum Geologists (AAPG) and the U.S. Geological Survey. Data are supplied on orders through AAPG.
4. The Mineral Resources Data Bank of the USGS/Reston (termed CRIB) currently has 31 000 records on file. CRIB is planned to contain geothermal resources as well as other mineral data.

References

1. "General Information Processing System (GIPSY)," GIPSY Documentation Series, Vol. II, User's Guide, The University of Oklahoma Office of Research Administration, October 1975.

2. F. C. Paddison, "Visit to Dr. Gene Collins ERDA/Bartlesville, Oklahoma," APL/JHU QM-76-156, 10 December 1976.
3. "Petroleum Data System of North America, User's Guide."

Visit to USGS, Menlo Park, CA

J. W. Follin visited Robert Christianson and his deputy, Robert Mallis, of the Geothermal Division, and Frank Trainer, of the Water Resources Division, on 14 December to discuss the APL program. Dr. Follin showed them the geothermal trip reports written by APL personnel. The general conclusion was that APL had not found anything new or unexpected. USGS will see if they can get geothermal temperature reports from the various surveys in which they are involved, but they do not expect much meaningful data because of the delays and extra expense involved in obtaining temperature profiles.

The revision of Circular 726 was discussed. USGS indicated that a format has not been established and the circular may not be issued merely as a revision. The scheduled publication date of December 1978 is too late to be of much help to APL. APL asked about the possibility of obtaining an early draft of the Region 5 portion of the report. USGS replied that, unless they could set up an open-file report, they doubted that the art work for at least one area of the country would be done in time to justify a preliminary release.

However, all of the geothermal data base that will be inserted in the revision of Circular 726 can be obtained from a data file called Geotherm, operated by James Swanson at Reston, VA. This program uses the same language as the Grid program; however, it was not intended that the two programs should overlap. Grid is restricted mostly to bibliographic information and Geotherm contains primary data. However, it appears that an overlap is developing between them. Mr. Swanson is transferring to Menlo Park next summer, but will probably keep the data base in Reston on an IBM 360 computer. If APL desires information from this data base, it can be obtained from Mr. Swanson.

USGS was shown the first draft of the Geothermal Glossary, and some of the editing changes that will be made were indicated. USGS was impressed by the comprehensiveness of the vocabulary contained in the Glossary, and felt that its publication would be useful.

The ELF analyses at APL were discussed. USGS thought it would be useful to make a proposal to Donald W. Klick at Reston. If APL wants a technical discussion on the subject, it should get in touch with Frank Frischknecht, Chief of the Electromagnetics and Geomagnetics Division of USGS, Denver. Mr. Klick will probably refer the proposal to Dr. Frischknecht for evaluation, but Mr. Christianson thought it might be a good idea to discuss it with him first.

APL discussed the possibility of geopressurized resources on the East Coast similar to those in Texas and Louisiana. Mr. Christianson thought that the sedimentation rate was probably insufficient to support such resources; however, he would be interested to hear of any potential locations that are suggested by George Fisher of the Department of Earth and Planetary Sciences of The Johns Hopkins University.

Finally, USGS has recently installed a Honeywell Series 60 Level 68 computer at Menlo Park. However, they do not plan to transfer their data base to it.

Status of USGS 1976 Atlantic Margin Coring Project

The USGS program of stratigraphic drilling on the margin of the Atlantic offshore continental shelf has been completed. A report is to be published shortly. Twenty-nine holes 1000 ft deep were drilled and cored at 19 geologic sites. Complete logs, including temperatures, were made on four holes; six additional holes had partial logs that did not include temperatures. Jack Hathaway, USGS, Woods Hole, MA, is the contact. See Refs. 1 and 2 for more detailed discussion.

References

1. F. C. Paddison, "Discussion with Dr. J. Hathaway, USGS, Woods Hole, Massachusetts," APL/JHU QM-76-078, 10 June 1976.
2. F. C. Paddison, "Status of USGS 1976 Atlantic Margin Coring Project," APL/JHU QM-76-154, 10 December 1976.

Deep Stratigraphic Drilling Offshore by Oil Consortium

A consortium of the offshore leasing oil companies has drilled two deep wells; one is drilled to a depth of 16 000 ft in the Baltimore Trench 90 mi off the Atlantic coast in water 289 ft deep; the second is in the Georges Banks off New England. Logs for the first hole, termed "Open File Report," are available. Logs of the second hole will be available to the public when leases for the Georges Banks are available. The temperature logs for these and subsequent holes will be compared with those being completed on the coastal plain by John Costain of Virginia Polytechnic Institute.

Visit to ERDA/Bartlesville, OK

Reference 1 documents a visit to Gene Collins of the ERDA/Bartlesville Laboratory. Dr. Collins is interested in chemical methods to enhance the recovery of oil. He collects data on the chemistry of oil-field waters and, with the help of the University of Oklahoma at Norman, is developing a subfile of oil and oil-field water chemistry, part of a USGS petroleum data system. See Refs. 1 and 2 for a detailed discussion. These data will be of interest if heat recovery from oil-field waters proves practical.

References

1. F. C. Paddison, "Visit to Dr. Gene Collins ERDA/Bartlesville, Oklahoma," APL/JHU QM-76-156, 10 December 1976.
2. F. C. Paddison, "Visit to Oklahoma," APL/JHU QM-76-158, 10 December 1976.

Visit to Richard Lassley of the Cities Service Co., Tulsa, OK

The AAPG in cooperation with the USGS has published a geothermal and subsurface temperature map of the United States. In addition, gradient maps of some individual states are also available. It is desirable to calculate the isotemperature contours in oil and gas formations where large amounts of water are contained in the oil. To this end Dr.

Lassley was visited to see if the same group of people who produced AAPG/USGS maps could extend their analysis to specific formations. Dr. Lassley has been made available by the Cities Service Co. to develop isotemperature contours in selected oil/water-bearing geologic formations. It is planned that representatives of the Oklahoma State Geological Survey will meet with Dr. Lassley and an ERDA representative to select the formations to be contoured. If this effort proves successful, similar efforts will be undertaken for other states.

A visit was also made to the Cities Service Operating Co. to determine if data on the quantity of water produced by each group of wells are available. These data, together with the temperature logs of the wells, could provide an estimate of the thermal energy available for use in states where oil or gas is produced. When provided by Cities Service, such data should illustrate what is available, county by county, in Kansas, Oklahoma, and Mississippi.

Reference 1 is a detailed discussion of the visit.

Reference

1. F. C. Paddison, "Visit with Dr. Richard Lassley, Cities Service Company," APL/JHU QM-76-157, 10 December 1976.

TECHNICAL STUDIES

Use of Extremely Low Frequencies to Measure Earth Conductivity at Depth

Most geothermal resource regions are characterized by their high electrical conductivities (about 1 mho/m). In the past, magnetotelluric (MT) methods have been used to probe the conductivities (or equivalently, the resistivities) of the underlying layers (Refs. 1 and 2). The MT methods measure the tangential E and H fields and infer the "surface" impedance tensor defined by $H_{\parallel} = ZE_{\parallel}$, where $E_{\parallel}$ and $H_{\parallel}$ are the surface fields (two components). In the one-dimensional model, impedance is a function of the frequency and the conductivities of the underlying layers. Hence the measurements at various frequencies lead to a determination of the conductivities.

Past MT investigations (for example, Ref. 1) used the MT fields in the frequency region of 10^{-4} to 10 Hz, probing the depths down to about 1000 km. Unfortunately, the MT signals are not coherent, rendering the required signal processing quite cumbersome. On the other hand, at the extremely low frequencies (ELF) (say, 45 to 75 Hz), the skin depths are typically in the neighborhood of 2 km (1.8 to 2.4 km); consequently, the electromagnetic (EM) signals in this region are ideally suited for probing the near-surface underground conductivities to about 3 km. Fortunately, there is a U.S. Government-owned facility that radiates coherent signals at 45 and 75 Hz.

To demonstrate the feasibility of applying such a method to detecting localized regions of anomalously high electrical conductivity, a study is in progress to calculate the horizontal component of the scattered field amplitude and phase at the surface. Based upon the results, a "for-instance" conceptual design of a phase-sensitive detector was made. The investigation shows that such a region of high conductivity (0.5 to 2 km deep) may be detected at a distance of approximately 5 to 10 km. The results are being documented. Based on this investigation, a suitable combination of LF, VLF, ELF, and the MT (1 to 10 Hz) method will yield a reliable method of mapping the underground conductivity in the region of prime interest (0 to 10 km deep).

References

1. See for example, D. R. Word, et al., Crustal Investigations by the Magnetotelluric Tensor Impedance Method, Geophysical Monograph Series, Vol. 14 (J. G. Heacock, Ed.), American Geophysical Union, 1971, pp. 145-167.
2. D. H. Bennett and J. H. Filloux, "Magnetotelluric Deep Electrical Sounding and Resistivity," Reviews of Geophysics and Space Physics, Vol. 13, No. 3, 1975, pp. 197-203.

Seminar on Appalachian Geology

On 18 November, George Fisher, Professor of geology at The Johns Hopkins University, delivered a seminar on the basic geology of the Appalachian and Coastal regions of the Eastern United States. Two representatives from the Mitre Corporation also attended.

Prof. Fisher's seminar provided valuable background material including a number of geological maps of portions of the Piedmont, Coastal, and Upland regions in Maryland, Pennsylvania, and Virginia. Perhaps most significant was his suggestion that the geology of the eastern Coastal region is not so very different from that of the Gulf Coast, and consequently the possibility of geopressured zones should not be dismissed.

Subcontract with Wright Associates

R. E. Wright Associates, Harrisburg, PA, are consultants on earth resources with considerable experience in mining geology, hydrology, and similar activities. A subcontract was signed with APL to provide consulting services, as needed, on Region 5 geological and hydrological questions. The subcontract will run for the Calendar Year 1977.

ENERGY CONSERVATION

The first law of thermodynamics guarantees energy conservation. "Reduction in the rate of consumption of scarce energy resources" is a more accurate statement of the objective popularly referred to as "energy conservation." Three distinct approaches to energy conservation with progressively longer implementation time scales follow from this definition. First, life styles can change to reduce demand. In this approach the technological innovations required are minimal, but the social and economic problems are difficult. This is the mode of energy conservation nature will force upon us if we do nothing to prevent an energy crisis. The second approach may also involve life-style changes. It is basically a technological change that increases the efficiency of energy utilization; i.e., the same or an equally attractive life style is maintained with less energy consumption. In this approach both product and system design technology innovation play a major role. The third approach is associated with the conversion of the consumed energy resource from the "scarce" to the "abundant" category. This can be accomplished either by substitution of an abundant energy supply for one that is scarce or by discovering dramatic new supplies or recovery processes.

As an energy consumer, APL has practiced the first approach to energy conservation. Like many industrial firms, APL has taken steps to reduce direct energy demands. APL has also reduced indirect energy demand by steps such as encouraging workers to car pool and recycle paper. In the second approach to energy conservation, APL has programs or proposals relating to more efficient modes of transportation, combustion, heating and cooling, energy transmission, and energy storage. APL is also active in the third approach with several studies of substituting solar energy for scarce fuels, some fusion analysis work, fundamental combustion studies pertinent to the better use of coal, and nuclear safety studies. Novel substitution energy sources such as ocean thermal energy and geothermal energy are also being investigated.

OPERATIONAL RESEARCH, GEOTHERMAL ENERGY §24
DEVELOPMENT AND UTILIZATION
Geothermal Program, Region 5 ZJ70CQO
Support: ERDA/DGE
F. C. Paddison and A. M. Stone
October-December 1976

STATUS OF GEOTHERMAL ENERGY IN THE COMMONWEALTH OF PUERTO RICO

The U.S. Geological Survey (USGS) Circular 726, "Assessment of Geothermal Resources of the United States, 1975," emphasizes known high-temperature geothermal resources. However, the lower temperature and normal-gradient characteristics of its Region 5 (the United States east of the Rocky Mountains, excluding Texas and Louisiana) are not discussed in detail. The Commonwealth of Puerto Rico is not specifically included in Region 5 by the USGS but, because of its special relationship to the United States, and with the concurrence of the Energy Research and Development Administration/Division of Geothermal Energy (ERDA/DGE), it was added to the region to be studied and evaluated.

Thus during the current survey of Region 5, in order to develop a base for predicting the possible use of geothermal energy as a function of time and to select the subregions for a near-term concentration of planning effort, the Geology Program Director in the Department of Natural Resources, Puerto Rico, was visited.

BACKGROUND

Puerto Rico's origin is not as well understood as that of the islands to the east, the Lesser Antilles. The Antilles are on the edge of the small Caribbean plate that is being subducted by the Atlantic plate. There are active volcanos on some of those Caribbean islands (Martinique and Guadeloupe) but not on Puerto Rico. Puerto Rico is a mixture of Cretaceous or Jurassic (less than 160 million years old) volcanic rocks, layered with sedimentary and limestone deposits. The center of the island is mountainous, composed of granitic rocks uplifted after they were formed under water. The north and south sides of the island consist of sedimentary deposits and limestone. On the northern side of the island the sedimentary deposits reach 1500 m in depth and the limestone 4000 to 5000 m. There are aquifers in the sedimentary layers, the recharge area being in the mountain rain forests where rainfall reaches 200 in./yr. The only thermal spring is a hot spring in the town of Coamo (Baños des Coamo). Here the water is in the 90 to 100°F range, and the flow is limited. The flow has decreased recently and the temperature has dropped 17°F since 1948. Little is known about the spring's hydrogeology. There are many faults with an east-west orientation in the island. One of the major faults is near Coamo. Lynn Glover (VPI) has published an extensive paper about the geology in the Coamo area (Ref. 1).

There are two massive batholiths, one in the eastern and one in the western part of the island. Copper deposits and highly mineralized deposits are present around the perimeter of the western body. There are drill holes about 1000 ft deep into these mineralized areas. Little is known about the geology beneath the surface of the island. A stratigraphic hole should be drilled in one of the batholiths and measurements taken of temperature, rock radioactivity, and thermal conductivity.

DISCUSSION

Ramon Alonso, the Geology Program Director, has been in office only six months. He is basically pessimistic in regard to geothermal prospects in Puerto Rico. Geologic studies are few, and recent ones were made only in connection with nuclear plant siting. No useful geothermal information is expected from these studies. Despite a violent earthquake in 1918, the island is claimed to be in a quiet orogenic zone, which is a little puzzling in view of the nearby subduction regions, the Antilles volcanism, the numerous midplate fault-slip lines, and the east-west slip fracture just north of the island.

Few holes have been drilled. One-thousand-foot holes were drilled into mineralized copper deposits by American Metals Climax. Four exploratory oil wells were drilled by Sun Oil Co. to 4000 to 5000 ft, three on the south side of the island and one on the north edge. No thermal data were taken.

A 1000-ft hole was drilled by USGS into a rare serpentinite body near Mayaguez. Thermal conductivity was measured and heat flow calculations were made (Refs. 2 and 3). Serpentinite is discussed in Ref. 4.

A meeting was also held with Ismael Almodovar, Director of the University of Puerto Rico Center for Energy and Environmental Research. Only a small amount of additional information was obtained (see Ref. 5).

REFERENCES

1. L. Glover, "Geology of the Coamo Area, Puerto Rico, and Its Relation to the Volcanic Arc-Trench Association," Geological Survey Professional Paper 636.
2. W. H. Diment, "Thermal Conductivity of Serpentinite from Mayaguez, Puerto Rico, and Other Localities," USGS report.
3. W. H. Diment and J. D. Weaver, "Subsurface Temperatures and Heat Flow in the Amsoc Core Hole Near Mayaguez, Puerto Rico," USGS report.
4. C. A. Burk (Ed.), "A Study of Serpentinite," National Academy of Sciences Publication No. 1188, 1964.
5. F. C. Paddison, "Geothermal Energy and Puerto Rico," APL/JHU QM-76-145, 2 December 1976.

OPERATIONAL RESEARCH, GEOTHERMAL ENERGY § 25
DEVELOPMENT AND UTILIZATION
Geothermal Program, Region 5 ZJ70CQO
Support: ERDA/DGE
F. C. Paddison and A. M. Stone
October-December 1976

STATUS OF GEOTHERMAL ENERGY IN THE STATE OF GEORGIA

The U.S. Geological Survey (USGS) Circular 726, "Assessment of Geothermal Resources of the United States, 1975," emphasizes known high-temperature geothermal resources. However, the lower temperature and normal-gradient characteristics of its Region 5 (the United States east of the Rocky Mountains, excluding Texas and Louisiana) are not discussed in detail. We understand that in the future the USGS will revise its reports to include these lower temperature regions. Currently, a survey is being made of Region 5 to develop a basis for predicting the possible use of geothermal energy as a function of time, and to select the subregions for a near-term concentration of planning effort. In that connection, a visit was paid to the State of Georgia Geological Survey.

BACKGROUND

The Director of the State Geology Office of the Department of Natural Resources, Georgia, is S. M. Pickering, Jr.

Georgia is composed of three primary regions: the Uplands, the Piedmont, and the Coastal Plain. The Uplands are folded mountains (the Appalachians) containing some sediments and many fault zones. There are many outcroppings of basement rocks. The Piedmont is heavily eroded and has exposed crystalline rocks. In the lower southeast portion of the state, the Coastal Plain, sedimentary deposits cover the crystalline basement rock. The sediments reach 500 ft at the sea coast. The basement rock falls away and the sedimentary cover deepens to the west.

The lower quarter of Georgia is underlain by a limestone formation that reaches a thickness of 800 ft near the Florida border. The formation carries a large volume of water into Florida (Wallahula Spring south of Tallahassee (Ref. 1), for example) and into the ocean via the continental shelf. The cities of Savannah, Brunswick, and St. Marys use this water for drinking, industrial cooling, and makeup, principally in the pulp and paper industries. Close to 400 million gal/day are used. The near-surface water is at 23 to 25°C. The shallow water aquifer is also used in Tallahassee for cooling state buildings. The draw-down attendant with the extensive withdrawal of water is very evident near these cities (see Ref. 2).

There are numerous large caves in Georgia, many containing marble that can be quarried. Cool air (55 to 60°F) is exhausted from these quarries and is also used for space cooling.

The basement of the northeast portion of the state contains Cretaceous rocks about 70 to 80 million years old. The basement was formed by Graben and Horst faults running north-northeast by south-southwest. Parts of these valleys are eroded and covered with sediments; some are only slightly weathered. Near the middle of the state, some of these structures are visible at the surface.

The age of the basement crystalline rocks found in the state is unknown. Triassic basins may be found in the southwestern part of the state. In the northeast, the age of the intrusive Cretaceous basalt was found from potassium-argon dating. There are two enormous gravity highs in the middle of the state, but no holes have been drilled into them. They probably are examples of intrusive basalt.

Reference 3, a prepublication paper, discusses pre-Cretaceous rocks under the Georgia Coastal Plain. Figure 1 shows locale and type of basement rock determined from oil and gas test wells drilled in Georgia and Northern Florida.

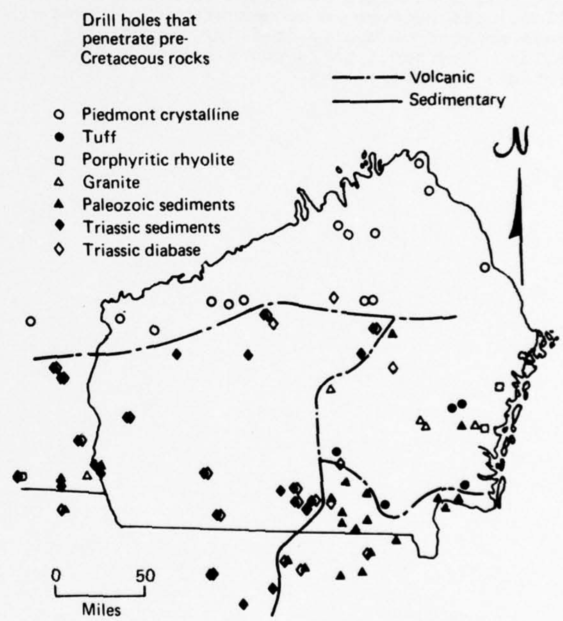

Fig. 1 Paleogeologic Map of Pre-Cretaceous Surface

One example of the commercial use of geothermal energy is a catfish farm in Savannah. There James Andrews of Skidaway Ocean Science Center is using 33°C water from an oil test well to increase the yield of catfish up to fivefold.

Drilling costs in Georgia in 1974 were approximately $60 per foot.

The Chief Hydrologist in Georgia is David F. Swanson. He maintains the logs of wells drilled there. The bottom-hole temperatures of 19 such wells have been determined with varying degrees of accuracy and have been used by the USGS Water Resources Division in developing their hydrological model (see below).

DISCUSSION

The USGS Water Resources Division/Georgia has all the available temperature logs for the oil wells in Georgia. Most are less than 1000 ft deep; only four or five are deeper. From the temperature-depth curves of 15 holes, a first-cut attempt at a geothermal gradient map has been made. Nothing appears to be above normal gradient (Ref. 4).

The State Office of Energy Resources within the Office of Planning/Budget is a recent creation. Its charter is conservation and alternate sources of energy (Ref. 5), especially solar. Its function is coordination and monitoring, not operations.

REFERENCES

1. "Geothermal Energy and Florida," APL/JHU QM-76-105, 18 August 1976.
2. *Hydrologic Atlas No. 1*, published by Georgia State Geological Survey.
3. T. M. Chowns, "Pre-Cretaceous Rocks below the Georgia Coastal Plain," West Georgia College, Carrollton, GA.
4. Thermal gradient maps are contained in an APL internal document (to be published).
5. S. Gonzales, "The Evaluation and Assessment of Geological Energy Resources in Georgia," University of Georgia, for State of Georgia Energy Office, December 1975.

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OPERATIONAL RESEARCH, GEOTHERMAL ENERGY DEVELOPMENT AND UTILIZATION §26
Geothermal Program, Region 5 ZJ70CQO
Support: ERDA/DGE
F. C. Paddison
October-December 1976

STATUS OF GEOTHERMAL ENERGY IN THE STATE OF IOWA

The U.S. Geological Survey (USGS) Circular 726, "Assessment of Geothermal Resources of the United States, 1975," emphasizes known high-temperature resources. The lower temperature and normal-gradient characteristics of ERDA/DGE Region 5 are not discussed in detail. We understand that in the future USGS will revise its reports to inlcude these lower temperature regions. Currently a survey is being made of Region 5 to develop a basis for predicting the possible use of geothermal energy as a function of time and to select the subregions for a near-term concentration of planning effort. In that connection the Iowa Geological Survey, Iowa City, IA, was visited on 7 October 1976.

SUMMARY

The State of Iowa has a relatively thin cover of sedimentary rocks that are quite porous. Accordingly, a considerable flow of underground water tends to moderate the few thermal gradients that have been measured to date. The result is that the thermal gradients for Iowa appear to be the lowest in Region 5. The thermal data on the state are very limited; further effort will be required to confirm the apparently low thermal gradient.

DISCUSSION

The subject of geothermal energy and the State of Iowa was discussed with D. Koch, F. H. Dorheim, and L. K. Kuiper.

Iowa is covered with sedimentary rocks that are thin in the northeastern corner of the state and increase in thickness, from 2000 to 3500 ft, across the state to the southwest corner. Figure 1 shows a geologic cross section of the state.

These deposits are not metamorphosed except near an intrusive pinnacle of Precambrian rock in the northwest region where surrounding sediments are weakly metamorphosed. There is a finger of this same material, i.e., magnetite gabbro and shale, that extends in the northeast direction. The pinnacle is 90 ft from the surface and is 12 by 15 mi in extent.

The Greenleaf granite, an anomaly from Minnesota, enters Iowa in the upper center, extends southward for about one-fourth of the state, and then turns to the southwest corner. This is part of the continental rift where igneous rock intruded, filling the rift zone, and pushed Precambrian sandstone (elastics) to each side.

The area is of interest to the Federal Energy Administration (FEA) since it represents a past tectonic area and borders on a region where several future nuclear and coal-fired power plants are planned. FEA is planning a

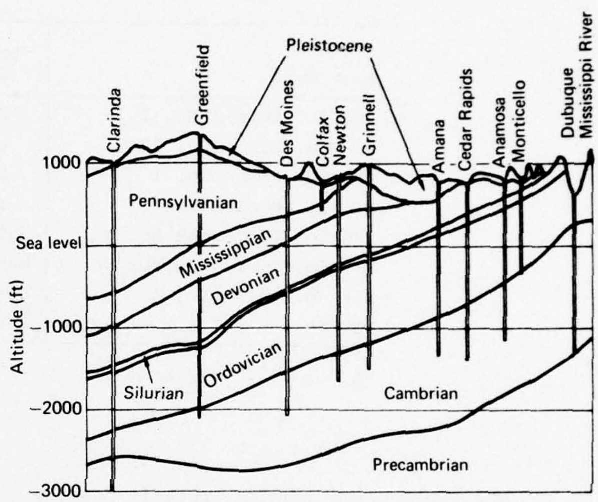

Fig. 1 Geologic Cross Section of Iowa. (76-4/12)

multistate drilling and seismic study to understand better future possible tectonic activity.

Iowa has not measured the thermal gradients nor calculated heat flows. In Ref. 1 there are heat-flow calculations of 0.44 heat flow units (HFU) (1.0×10^{-6} cal/cm^2-s) and a low thermal gradient of 8.3°C/km. These measurements were made near the town of Spencer (Clay County) in a well approximately 2200 ft deep into the basement.

Some 1964 data taken by J. Combs of MIT for a series of wells in Dallas County (near Des Moines) and the southeast corner counties of Washington and Louisa are shown in Table 1.

These data came from holes drilled into anticlines in sand formations for locating gas storage sites. Some of these sites are currently in use.

Iowa has not attempted any systematic survey of thermal gradients or temperatures of aquifers. In preparation for our visit, they compiled the list of bottom-hole temperatures in Table 1. Measurements are difficult in Iowa since the lower formations are very thick sandstone (1000 ft) that apparently all carry water. The water flow is from west to east.

Table 1
Calculated Heat Flow Values

Test Well	Location (County)	Depth (ft)	Bottom-Hole Temperature (°C)	HFU*
NNG Co. Hofman No. 1	Dallas	2266	17.69	0.87
NNG Co. Olson No. 1G	Dallas	2333	18.92	0.89
NNG Co. Price No. 1	Dallas	1918	21.84	1.23
NNG Co. Book No. 1	Dallas	2225	23.53	1.24
NNG Co. Broderick No. 1	Dallas	1200	17.28	1.25
NGP Co. Amer Anderson No. 1	Washington	1200	22.82	1.53
NGP Co. Vogel No. 1	Washington	1162	22.92	1.55
NGP Co. Hutchinson No. 2	Louisa	855	16.43	1.77

*1.0×10^{-6} cal/cm^2-s

The Precambrian basement rock is heavily weathered and hydrothermally altered. One drill hole near the town of Spencer, Clay County, is 2200 ft deep and into the basement rock. No temperature data other than a thermal gradient of 8.4°C/km are available.

There is essentially no oil or gas in Iowa. Although oil was discovered in Keokuk County in an Ordovician age formation, only six barrels of 24-weight specific gravity oil were recovered in a period of six weeks. Some coal is strip mined. Deposits of lead and zinc are located in the eastern part of the state.

There is water in most of the sediments underlying the state. These aquifers appear to conduct heat away. It is not likely that any useful geothermal sources exist in Iowa.

REFERENCE

1. R. F. Roy et al., "Heat Flow in the United States," J. Geophys. Res., Vol. 73, No. 16, 15 August 1968, pp. 5207-5221.

UNCLASSIFIED

OPERATIONAL RESEARCH, GEOTHERMAL ENERGY DEVELOPMENT AND UTILIZATION §27
Geothermal Program, Region 5 ZJ70CQO
Support: ERDA/DGE
F. C. Paddison
October-December 1976

STATUS OF GEOTHERMAL ENERGY IN THE STATE OF KANSAS

The U.S. Geological Survey (USGS) Circular 726, "Assessment of Geothermal Resources of the United States, 1975," emphasizes known high-temperature resources. The lower temperatures and normal-gradient characteristics of ERDA/DGE Region 5 are not discussed in detail. We understand that in the future USGS will revise its reports to include lower temperature regions. Currently a survey is being made of Region 5. In that connection the Kansas State Geologic Survey, Lawrence, KS, was visited on 19 October and again on 20 December 1976.

SUMMARY

Although there have been no heat flow studies in Kansas, 250 000 holes were drilled to provide water, oil, and natural gas. The amount and temperature of the water varies considerably; however, particularly in the western portion of the state, water temperatures are found that are of possible interest for space heating or agricultural crop drying and/or processing.

DISCUSSION

The first meeting on 19 October 1976 was with W. Hambleton, O. Spitz, and D. Steeples of the State Geologic Survey. The second meeting was a workshop that was attended by many of the Survey Staff, representatives of the Kansas Office of the U.S. Geological Survey Water Resources Office, Jerry Bradley of the Midwest Research Institute, and M. Lucas of Kansas State University.

Status of Geothermal Energy Programs in Kansas. There have been no heat flow studies in Kansas. A study of basement rock is under way; however, studies of temperatures and heat production are not included. Thermal conductivity of the sedimentary cover has not been measured. The Survey is interested in heat flow studies and their correlation with aeromagnetic, gravity, and seismic studies.

Kansas is participating in the ERDA lineaments study for uranium but not in its groundwater chemistry program. Kansas is a partner with Oklahoma and Nebraska in the NRC (Nuclear Regulatory Commission) seismic network for a tectonics study of the Nemaha uplift.

It is of interest that there are 250 000 drill holes in the state. The survey has records and cuttings or cores for about half. Most of the wells were drilled into an Ordovician limestone formation, the Arbuckle. There are substantial fields of both oil and natural gas in this formation. The state is a net exporter of energy (although it refines Canadian crude). Apparently in the central and eastern parts of the state, farmers drill their own gas wells. Although the gas pressure is low, 5 psi in many of the wells, that is apparently no detriment. In the oil fields in the western section of the state (the southwest Kansas Basin), water is mixed with the oil, approximately nine parts of water for each part of oil. The water is separated and returned to the ground with make-up water from shallower aquifers for field pressurization. Most of the wells are on secondary recovery, and tertiary recovery is being considered. As one might expect, most of the wells are in the western part of the state, and the population density is low; however, there are some holes almost everywhere. In the eastern region they are much shallower, i.e., 1500 to 2000 ft deep, and the water temperature is 90°F. The holes in the west are 3000 to 5000 ft deep and the water is much hotter, 150°F. However, there are deeper aquifers than the Arbuckle. For instance, in the oil fields in the center of the Hugoton Embayment, the depth of sediments is 15 000 ft. If there are deeper aquifers, the extension of existing wells for geothermal purposes may be interesting.

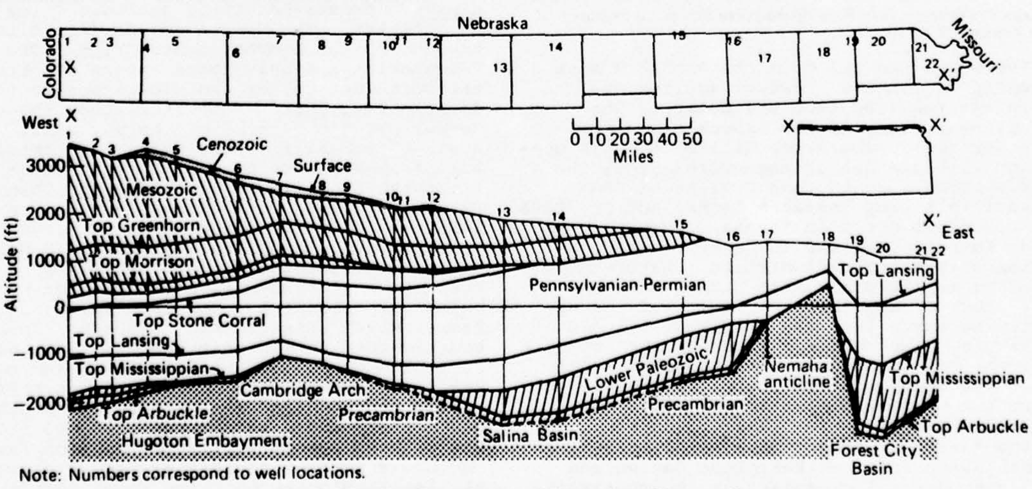

Fig. 1 West-East Cross Section of Kansas from Cheyenne County to Doniphan County Showing Stratigraphic Relation of Major Units. (76-4/17)

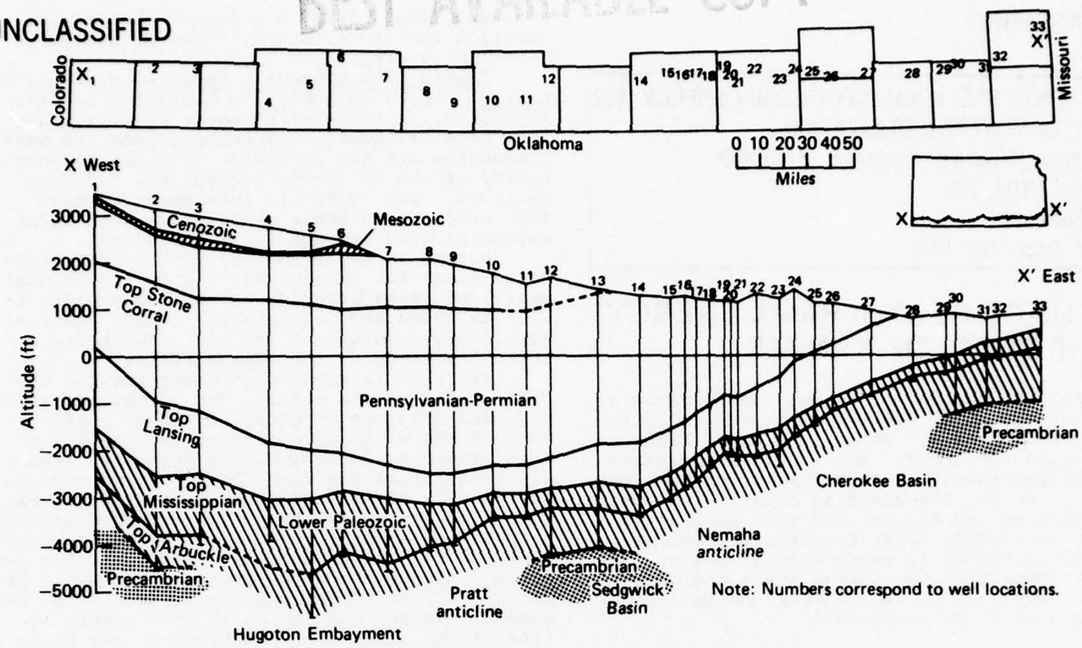

Fig. 2 West-East Cross Section of Kansas from Morton County to Crawford County Showing Stratigraphic Relation of Major Units. (76-4/18)

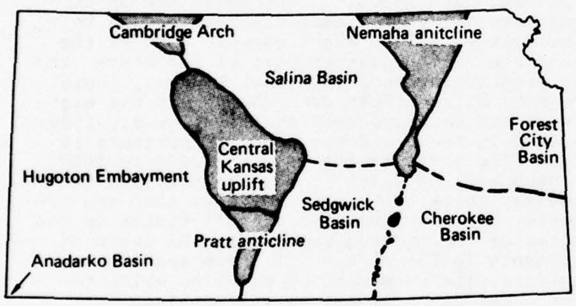

Fig. 3 Major Pre-Desmoinesian Post-Mississippian Structural Features of Kansas. (76-4/19)

The water and oil from the Arbuckle were apparently from a low-pressure aquifer, so pumping was required from the outset. The state plans a study of the Arbuckle and its waters (brines). The study will be made in conjunction with a model of the hydrology of the Arbuckle being made by Gene Collins of ERDA Bartlesville Energy Research Center and the USGS Water Resources Group in Kansas. They plan to include temperatures and temperature effects on the viscosity of the oil mixture. Water-dating and helium analysis are also included in the study. Much of the thrust of the study is apparently research into the origin of oil and natural gas. The recharge area for the Arbuckle is thought to be the Ozark and Arbuckle Mountains. The study will be useful in any plan to utilize the thermal properties of oil field waters.

The thermal gradient maps supplied by the American Association of Petroleum Geologists (AAPG) show several anomalies in the southwestern part of the state for which there is no geological explanation. The state is planning further aeromagnetic surveys of the entire state. There appears to be a correlation between magnetics and the AAPG gradient maps.

The Survey will examine bottom-hole temperature data supplied to AAPG.

The Ogallala water availability study just completed is a model of what the state plans to do in defining the Arbuckle aquifer. The Ogallala is a shallow formation of Tertiary sand and gravel that covers most of the state and in particular the western region, the area most interested in irrigation water. The annual rainfall varies from 35 to 15 in./yr from eastern to western Kansas.

Brief Overview of Geology of the State of Kansas. Kansas has three geologic formations of interest. The Nemaha uplift (anticline) is the end of the midcontinental rift. The faulted Precambrian intrusive mass enters the state in the northeast corner and progresses southwest, disappearing just before it reaches the Oklahoma border about one-third of the way west. In the northwestern half of the state the Cambridge Arch from Nebraska enters the state. It becomes first the Central Kansas uplift and then the Pratt anticline, which disappears before the Oklahoma border is reached. The direction of this system is opposite that of the Nemaha, i.e., southeastern. In the western part of the state is a plateau called the Hugoton Embayment, before the basement drops into the Anadarko Basin, which extends into Colorado. In the southwestern region of the state the basement rock plunges to the Anadarko Basin and continues to Oklahoma. (In Kansas this is still termed the Hugoton Embayment.) The depth of sedimentary rocks here reaches 15 000 ft. Figure 1 shows a west-east cross section through the upper part of the state; Fig. 2 shows a similar section through the lower portion of the state. The Cambridge Arch and the Nemaha anticline are clearly evident. Figure 3 shows a plan view of these systems.

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DEVELOPMENT AND UTILIZATION
Geothermal Program, Region 5 ZJ70CQO
Support: ERDA/DGE
F. C. Paddison
October-December 1976

STATUS OF GEOTHERMAL ENERGY IN THE STATE OF MINNESOTA

The U.S. Geological Survey (USGS) Circular 726, "Assessment of Geothermal Resources of the United States, 1975," emphasizes known high-temperature resources. The lower temperature and normal-gradient characteristics of ERDA/DGE Region 5 are not discussed in detail. We understand that, in the future, USGS will revise its reports to include these lower temperature regions. Currently, a survey is being made of Region 5 (a) to develop a basis for predicting the possible use of geothermal energy as a function of time and (b) to select the subregions for a near-term concentration of planning effort. In that connection, APL visited the Minnesota Geological Survey, University of Minnesota, 1633 Eustis Street, St. Paul, MN 55108, on 5 October 1976.

SUMMARY

It is not apparent that the State of Minnesota has any geothermal potential; however, there are areas that may have large deposits of well-insulated radioactive materials where holes have not been drilled.

Since there are only six deep holes in the entire state, little data are available on thermal gradient or heat flow. However, Minnesota now plans to measure thermal gradient and heat flow in a 4000-ft gas storage test well near the Twin Cities.

Approximately 80% of the state is covered with sand and gravel deposits 200 to 600 ft thick, called glacial drift. These deposits are primarily in the northern, eastern, and southern portions of the state. Since there are few deep bore holes and limited surface exposures of underlying rock, much reliance for subsurface geology is placed on magnetic and gravity surveys. There are up to several hundred feet of silt and clay deposits of the Mesozoic period over the western part of the state. In the southeast and northeast corners, marine (fossiliferous) deposits of the Paleozoic era occur. In one place, a basin in the southeast portion of the state, they reach a depth of 640 ft. The rest of the state is composed of five terrains of Precambrian rocks ranging in age from 1.1 to 3.8 billion years. The latter group represents the oldest known earth rocks. These old rocks extend to depths of 3300 to 6500 ft.

Heat Flow and Thermal Gradient. Dr. Robert Roy of Purdue University measured heat flow in a 2000-ft hole at Ely, MN, and obtained a value of 1.0 heat-flow units (HFU). The thermal gradient was normal. A second measurement is now planned in a 4000-ft gas storage test hole near the Twin Cities and near the edge of the animikie group. Dr. George Shaw of the University of Minnesota Physics Department will perform the thermal gradient measurement.

Continental Drilling Program. At a meeting in 1974, the National Academy of Sciences proposed a deep continental drilling program similar to the ocean drilling program (Ref. 2). Minnesota suggested several sites for consideration (Ref. 3). Obviously, it seems logical for the Geothermal Branch to join this program to ensure that its interests are represented. F. M. Shoemaker of Cal Tech is the contact.

Geothermal Prospecting for Uranium. The Grand Rapids Office of ERDA has a joint program with several state geology offices to provide definitions of all aquifers and to receive samples of surface and deep waters collected in their state. The definition is well advanced and was scheduled to be completed by the end of December 1976. The principal aquifer is in the southeastern basin of the state, where there are deep sedimentary and limestone deposits. The samples will be collected by Bendix Engineering; Oak Ridge National Laboratory will perform isotope and chemical analysis of all the water samples while looking for uranium deposits. No radioactive dating or thermal history is planned. Once again, this appears to be a program that ERDA/DGE should join early to ensure that its interests are addressed.

The Minnesota survey wishes to do more to assess the geothermal potential within the state and, accordingly, may make a proposal to ERDA to support jointly a systematic survey of wells and mining; the state may then propose thermal gradient measurements and heat-flow calculations.

Summary of Deep Holes

1. Northeast corner of the state, near the town of Ely, 2000 ft deep. R. Roy measured a heat flow of 1 HFU.
2. In the northwest corner, near the town of Hallock, 500 ft deep in Mesozoic; no thermal data available.
3. Holes along the Mesabi iron range dipping at an angle of 12° into metasedimentary iron formation rocks 2000 to 3000 ft deep in the mid-northeast region of the state; no thermal data available.
4. Mid-eastern region near the Twin Cities, 4000-ft-deep well into Ordovician dolomite that was drilled for possible underground storage of natural gas. It is planned to fill the hole with bentonite; R. Roy and G. Shaw will measure the heat flow.
5. A 1640-ft stratigraphic hole was drilled through sediment (640 ft) and into the basement rock in a southeastern basin. The hole is now plugged; no thermal measurements were made.

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1. M. Walton, "Prospects for the Future Discovery of Mineral Resources in Minnesota," Reprint Series 31, address given at the 37th Annual Mining Symposium, Duluth, MN, 15 January 1976.
2. G. A. Swann (USGS) and E. M. Shoemaker (Cal Tech), "Deep Continental Drilling," Ghost Ranch Group, U.S. Geodynamics Committee, National Academy of Sciences, Carnegie Institute, Washington, DC, June 1974.
3. G. B. Morey, "The Basis of a Continental Drilling Program in Minnesota," Minnesota Geological Survey, Information Circular II, University of Minnesota, 1976.

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DEVELOPMENT AND UTILIZATION
Geothermal Program, Region 5 ZJ70CQO
Support: ERDA/DGE
F. C. Paddison
October-December 1976

STATUS OF GEOTHERMAL ENERGY IN THE STATE OF MISSOURI

The U.S. Geological Survey (USGS) Circular 726, "Assessment of Geothermal Resources of the United States, 1975," emphasizes known high-temperature resources. The lower temperature and normal-gradient characteristics of ERDA/DGE Region 5 are not discussed in detail. We understand that in the future USGS will revise its reports to include these lower temperature regions. In that connection, the Geological Survey, Rolla, MO, was visited on 30 November 1976. A meeting was held with Dale Fuller, State Geologist. Mr. Fuller made available the information discussed below.

SUMMARY

Missouri appears to lack any short-term potential for geothermal energy. Some effort is desirable to define the temperatures versus depth in the Precambrian and Cambrian basement rock.

DISCUSSION

In Missouri the igneous Precambrian rock is covered with a rather thin cover of sedimentary rock, except in the southeast corner where these granitic basement rocks are exposed at the surface. The surface of the basement rock is heavily weathered. The rock drops away gradually to the west and northwest, but more rapidly to the east, north, and south.

There are no known studies of these rocks as sources of geothermal energy.

The sedimentary rocks, which have not been metamorphosed, vary in depth from the outcropping of the basement to 500 to 600 ft to the northwest and west and to 3000 ft along the northern edge of the state. The depth increases to 7500 ft in the southeastern corner of the state.

The sedimentary rocks in the state are largely dolomite and sandstone. Many of the formations, together with the surface rocks, are very permeable; accordingly, there are many subsurface aquifers throughout the state. The waters are considered hard (250 on a relative scale); however they only contain 200 ppm of total solids. Mr. Fuller feels that the flow of these ground waters is substantial enough to moderate the state thermal gradients.

The northern portion of the state is capped with a cover of Pennsylvanian-age sediments covered with glacial till. The Pennsylvanian-age rocks are very impervious to water and the deep ground water is salty. Consequently there are few drilled holes in that region of the state.

The American Association of Petroleum Geologists (AAPG) maps of the U.S. showed no data on thermal gradients or temperatures for Missouri, since no oil well data are available. Mr. Fuller has prepared his own thermal gradient map from data that are available (Fig. 1). The number in the rectangular box is the thermal gradient and, at best, is 40% below the normal. The number under the box is the depth of the well whose data were used in the gradient calculation.

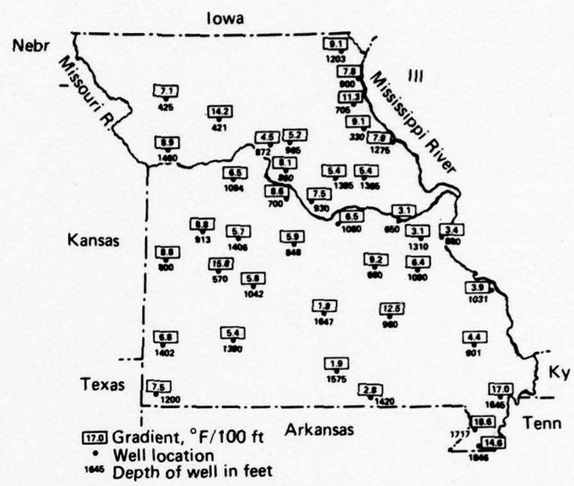

Fig. 1 Thermal Gradient as Measured from Water Wells in Missouri

Missouri is one of the leading lead producers in the U.S. The lead deposits are in sedimentary rocks lying in a belt running north and south, the belt being located in the mid-southeast corner of the state and to the northwest of the outcropping of the basement.

Missouri claims approximately 3000 caves, more than any other state.

Missouri has two deep (1300-ft) iron ore mines in Precambrian rock. They are located in the southeastern corner of the state where Precambrian basement rock is exposed. The iron ore body is similar to the Swedish iron ore deposit in Kiruna, Sweden, and was probably emplaced in a similar manner.

There are not many holes other than exploratory holes for mining, a few deep-water wells, and a DoD hole near the Minuteman missile silo farm. The bulk of them are in the southern part of the state.

Missouri is not participating in the ERDA uranium prospecting program through chemical analysis of sediments and ground water samples or in the continental drilling program.

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DEVELOPMENT AND UTILIZATION
Geothermal Program, Region 5 ZJ70CQO
Support: ERDA/DGE
F. C. Paddison
October-December 1976

STATUS OF GEOTHERMAL ENERGY IN THE STATE OF NEBRASKA

The U.S. Geological Survey (USGS) Circular 726, "Assessment of Geothermal Resources of the United States, 1975," emphasizes known high-temperature resources. The lower temperature and normal-gradient characteristics of ERDA/DGE Region 5 are not discussed in detail. In the future, USGS will revise its reports to include these regions of lower temperatures. Currently a survey is being made of Region 5 to develop a basis for predicting the possible use of geothermal energy as a function of time and to select the subregions for a near-term concentration of planning effort. In that connection, the Nebraska State Geologic Survey, Lincoln, NB, and the State Energy Coordinator were visited on 5 October 1976. The Office of the State Energy Coordinator and the Energy Office were established by Executive Order rather than by legislative act.

SUMMARY

No studies have been made of thermal resources in the State of Nebraska. However, there are 1200 oil or gas wells in the state that can provide data on thermal gradients in the areas where these wells are concentrated. From data supplied by the Geologic Survey to the American Association of Petroleum Geologists (AAPG) for analysis of thermal gradients, there is no evidence of hot spots in the state. Therefore, it appears that utilization of geothermal energy in Nebraska must depend upon the normal thermal gradient.

The fact that there are 1200 oil and gas wells provides an opportunity to use the thermal energy from oil field waters or possibly to extend these wells to deeper and hotter aquifers. The depth of the sedimentary cover over Precambrian basement rock in Nebraska is 3000 to 4000 ft; accordingly, water temperatures are expected to be moderate.

DISCUSSION

Discussions of geothermal energy in Nebraska were held with R. R. Burchett of the Geologic Survey and separately with W. Peters and G. J. Dworak of the State Tax Commissioner's Office.

Geologic Survey. Nebraska is underlain by relatively flat, weathered Precambrian basement rock that is 1000 ft deep in the east and 5500 ft deep in the west. The basement rock is covered with a layer of Tertiary (or Cretaceous) rock up to 3000 ft thick, a thin Jurassic layer (200 ft), 1000 ft of Permian, 1000 ft of Pennsylvanian, then Mississippian, Ordovician, and Cambrian. Few of these are metamorphosed except for the Sioux quartzite deposit in the upper eastern area.

There are several arches or domes in the sedimentary cover where oil is found. One of these is the Chadron-Cambridge Arch, which has a limited oil field at a depth of 3800 ft. Oil is contained in the Pennsylvanian and Reagan sandstones close to the basement rock.

Samples of basement rock from the Cambridge Arch are available. However, no heat-flow studies, radioisotope measurements, or thermal-gradient studies have been done for the state. Although no thermal waters are known, a report of thermal waters in a farm well in the town of Lynch (Holt County) in the northeast part of the state will be investigated.

The Geologic Survey has provided a data file of oil and stratigraphic hole depths and bottom-hole temperatures to the AAPG for use in developing the thermal gradient maps. The Survey has not analyzed these data for its own edification.

Most of the 1200 oil wells in Nebraska are found in the Panhandle region of the state in a portion of the Denver Julesburg Basin that extends into Colorado. The oil is found in Cretaceous sediments at approximately 3000 ft. Some water is mixed with the oil found in the Cambridge Arch, but little or none is in the Panhandle field. The Madison formation, which carries water, is 1000 to 2000 ft below the oil strata. No data are available on these waters.

Natural gas is produced in 19 wells. There is a small field in Ewel County, much of which is depleted, although some old wells are being used for gas storage.

Since only a few of the oil wells are artesian, blowout protection is not required. When oil production is completed, a plug must be put in above the oil strata; the hole is then filled with mud and plugged just below the surface.

When stratigraphic holes are drilled, the driller provides cuttings to the Survey. Logs of self-potential and resistivity must be filed and bottom-hole temperatures reported. A typical bottom-hole temperature for the oil wells in the Panhandle is 140°F at 6000 ft. An exploratory well in Holt County (Lynch) shows 100°F at 2865 ft.

Radioactivity. ERDA, through Bendix Engineering, is collecting soil and water samples in its search for uranium along lineaments observed by the Earth Resources Satellite. Nebraska proposes to buy gamma-ray logging tools and examine shallow (50- to 200-ft) depths near or along these lineaments. Uranium has been found in a region of the upper Panhandle. The area has a high concentration of 70% volcanic glass and some carbonaceous material. A uranium company has done some exploration.

ERDA, Grand Junction, CO, in its uranium geochemical prospecting program, has asked each state to identify aquifers and to supply samples of their waters. Nebraska has not yet responded to this program. Mr. Burchett suggests that water and soil samples be taken in selected areas based on gamma-ray logs of shallow wells.

There is a current program for drilling shallow holes on 12-mi centers east and west and 3-mi centers north and south over most of the state. Mr. Burchett recommends that the state acquire a gamma-ray log and look for radioactivity in all of these holes.

There has been tectonic activity on the eastern border of the state along the magnetic and gravity anomaly part of the midcontinent rift, i.e., the Greenleaf anomaly. An active study is being made of this area as part of siting studies for new nuclear and coal electric generating plants.

There are many aquifer systems in Nebraska in the Pliocene, Ogallala, Greenhouse, Dakota, Permian, and pre-Pennsylvanian formations. They are not used much since irrigation water (one farm acre out of four is irrigated) is drawn either from the rivers or from shallow wells.

There is an intrusive carbonatite of dolomitic limestone and granite similar to South African diamond pipes that is located in the southeast corner of the state at a strong gravity anomaly. The Molybdenum Corp. of America and the COMINCO American Corp. both have drilled in this mass. We do not know whether radioactivity or temperatures were logged.

Nebraska produces oil and a limited amount of natural gas; however, the state is a net importer of both. Some coal exists at 3000 ft but is not mined. The primary emphasis of the Energy Office to date has been conservation. The primary energy user is agriculture.

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Geothermal Program, Region 5 ZJ70CQO
Support: ERDA/DGE
F. C. Paddison
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STATUS OF GEOTHERMAL ENERGY IN THE STATE OF NORTH DAKOTA

The U.S. Geological Survey (USGS) Circular 726, "Assessment of Geothermal Resources of the United States, 1975," emphasizes known high-temperature resources. The lower temperature and normal-gradient characteristics of ERDA/DGE Region 5 are not discussed in detail. We understand that, in the future, USGS will revise its reports to include these lower temperature regions. Currently, a survey is being made of Region 5. In that connection, the North Dakota Geologic Survey (NDGS), Grand Forks, ND, was visited on 4 October 1976.

SUMMARY

The Madison formation underlies much of North Dakota, as it does South Dakota (Ref. 1). In the western portion of the state it plunges into a deep basin called the Williston Basin, which is shared with Montana, Saskatchewan, and Manitoba. There are two prominent oil-producing anticlines in the basin, the Cedar Creek and the Nesson. The oil comes primarily from the Madison formation, which reaches a thickness of more than 2000 ft in the center of the basin. In North Dakota, approximately 6000 holes have been drilled. Of course, most of them are along the anticlines and other formations where oil might be found; however, there are so many holes drilled in the state that at least one can be found close to most population centers.

An interesting possibility is that, when oil recovery ceases to be profitable, some of the holes might be refurbished and used for geothermal heat production. Originally the wells were artesian; however, with the extensive development of the field, the pressure has fallen and most wells have to be pumped. To minimize pumping, the brackish water is separated from the oil, additional Dakota formation water is added, and both are reinjected into the Madison. In time, the formation pressure will increase as oil removal lessens.

DISCUSSION

In the western part of the state, the Precambrian basement rock is located in the Williston Basin at a depth of 16 000 ft. The basement rock rises rapidly toward the east and is exposed at the east edge of the state. Sedimentary deposits and glacial till cover the basement rock. There are 6000 deep oil wells drilled in North Dakota. Of these, 2500 are producing. There are 600 shut-in wells resting, which are to be reopened at a later date. Many wells are drilled into the Dakota formation to obtain water for reinjection with water separated from oil in order to maintain field pressure and for secondary recovery. Salt is often added to drilling mud to minimize the erosion of salt layered/sedimentary salt formations as drilling progresses through these deposits.

The current rate of oil well drilling is approximately 20 new wells per year at a cost of approximately $1 million per well (if completed and put into production). Production has been so extensive that, in most of the fields, well pressure has lowered the standing head of the well to below the surface; accordingly, most are pumped.

It appears that when oil production of wells ceases, many of the wells could be used to supply thermal waters. Many of the holes are near population centers.

There are numerous aquifers under North Dakota. The Madison, one of the largest, carries the bulk of the petroleum production. It is also one of the thickest formations. These aquifers are so deep that the temperatures are all in the range of interest to the geothermal program.

Richard Scattolini, a graduate student whose PhD thesis is the extension of the calculations of heat flow by Decker and Roy (Ref. 2) for North Dakota, has obtained samples of basement rock. USGS/Denver has measured the concentration of radioactive materials and calculated heat production values. Dr. Scattolini and Professor Francis Hull of the Department of Physics, University of North Dakota, have measured the thermal profiles of a series of stratigraphic and other holes where little oil was found. Professor Hull was measured the thermal conductivity of drilling cuttings in a water slurry.

The Physics Department of the University of North Dakota has developed a technique for on-site measurement of thermal conductivity. The technique uses a device that seals a 5-ft section of a cased hole that is allowed to heat up. The heating rate is proportional to the local thermal conductivity. The investigators feel that the accuracy is within 10%.

Heat production values of the 10 basement rocks submitted by North Dakota to USGS/Denver gave values of 0.95 to 6.0 heat production units.* Thermal gradients vary from 30 to 48°C/km. Heat flow units† vary from 1.7 ±0.17 to 2.21 ±0.53. Dr Scattolini does not compensate in his calculations for connective transfer into or out of the area due to aquifers; however, it is apparent from well logs that aquifers in North Dakota do affect thermal gradients. Dr. Scattolini would appreciate any suggestions as to how to handle water aquifers in these types of calculations.

Much of the work on heat flow has been done by Dr. Decker of the University of Wyoming. The values Dr. Scattolini has estimated indicate that North Dakota has a higher heat flow per heat production unit than is indicated in published data for the Basin and Range Province. The discrepancies will be investigated.

ERDA is sponsoring a stratigraphic drilling program into basement rock in eastern North Dakota under Walter Moore of the Geology Department of the University of North Dakota. Basement rocks are relatively shallow (100 to 400 ft) in this area.

The North Dakota survey is providing data to the USGS/Denver Madison Formation Study. The study did not plan to include much of the Williston Basin in its analysis of the Madison, since there apparently is some evidence that the Madison is choked between the two states.

The following table gives some sample depths and temperatures of oil wells along the Nesson anticline.

*Heat production unit = 10^{-13} cal/cm^3-s
†Heat flow unit (HFU) = 10^{-6} cal/cm^2

Well NDGS	Well Depth ($ft \times 10^3$)	Bottom-Hole Temperature (°F)
33	11.3	319
35	7.5	190
50	6.0	149
555	8.8	230
--	13.3	280
586	9.1	200
591	5.9	144

FUTURE PLANS

The state survey has a compilation of the water analyses from many of the wells. The data also list water temperatures. It is recommended that a detailed compilation of these data be made to provide isotemperature and isopressure (shut-in) contours for each aquifer system.

The use of an oil well for geothermal heating after oil production is no longer cost-effective should be considered.

REFERENCES

1. R. F. Roy et al., "Continental Heat Flow," The Nature of the Solid Earth, E. Robertson (Ed.), pp. 506-544.
2. Section 1, Quarterly Report, July-September 1976, APL/JHU EQR/76-3.

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OPERATIONAL RESEARCH, GEOTHERMAL ENERGY DEVELOPMENT AND UTILIZATION §32
Geothermal Program, Region 5 ZJ70CQO
Support: ERDA/DGE
F. C. Paddison October-December 1976

STATUS OF GEOTHERMAL ENERGY IN THE STATE OF OKLAHOMA

The U.S. Geological Survey (USGS) Circular 726, "Assessment of Geothermal Resources of the United States, 1975," emphasizes known high-temperatures resources. The lower temperature and normal-gradient characteristics of ERDA/DGE Region 5 are not discussed in detail. We understand that, in the future, USGS will revise its reports to include these lower temperature regions. Currently, a survey is being made of Region 5. In that connection, the Oklahoma State Geologic Survey, Norman, OK, was visited on 2 October 1976.

SUMMARY

There do not appear to be any anomalous thermal gradients in the state of Oklahoma; accordingly, geothermal potential would appear to be based on the normal gradient of that area. Oklahoma has 300 000 oil and gas wells, many at depths that produce hot waters together with oil or gas. Thus, Oklahoma has a near-term potential, through the use of these oil field waters, for geothermal space heating and the many agricultural processes that can use moderate temperatues.

DISCUSSION

The consideration of geothermal energy and the state of Oklahoma was discussed with J. F. Roberts and Kenneth Lusa of the Geologic Survey. In addition, Charles Hill, Deputy of the State Energy Office, was contacted by telephone. They provided the following information.

There are no known abnormally high thermal gradients in the state of Oklahoma. The state is very complex geologically. Cambrian and Precambrian basement rocks surface at the Wichita and the Arbuckle Mountains. The state is heavily faulted in the southern and eastern regions and more than half of the oil reserves are from stratigraphic traps caused by fault zones. The Nemaha rift is still in evidence in northern Oklahoma, running almost due north and south and disappearing just under the town of Norman. There are three very deep (25 000 to 30 000 ft) basins containing oil: the Anadarko, the Ardmore, and the Arkoma. There are more than 300 000 oil and gas wells in the state. Oil comes from many formations. Most of the oil is not water-driven. Figure 1 illustrates the major oil and gas producing regions of Oklahoma.

For detailed information on water production and temperatures from oil holes, we were referred to operating oil companies and to Jerlene Bright, Director of Information Systems Programs, Office of Research Administration,

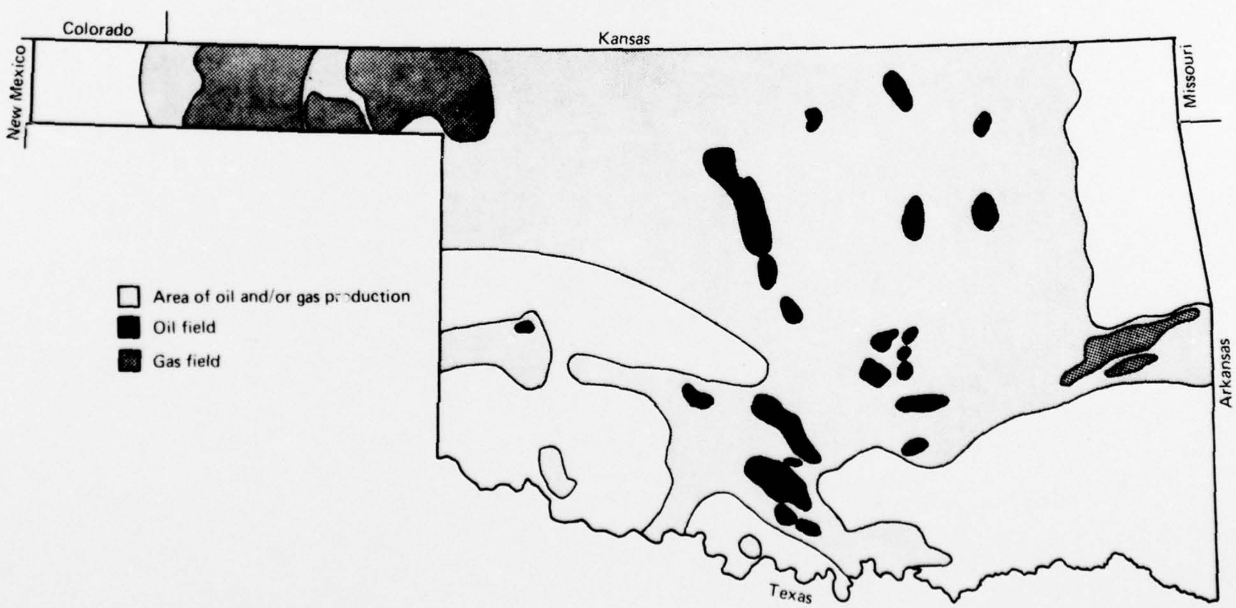

Fig. 1 Generalized Oil and Gas Map of Oklahoma. (76-4/16)

University of Oklahoma. The University is developing and will be the repository for the Petroleum Data System of the U.S. Geological Survey/Reston.

References 1 and 2 contain interesting data on the Arbuckle Mountain formations.

State Participation in the Tri-State Seismic Study. Kenneth Lusa briefly outlined a tri-state (Oklahoma, Kansas, and Nebraska) program funded 80% by the National Regulatory Agency (NRA) to define the tectonics of the region.

The three surveys will analyze all pertinent geological data. Although primary emphasis will be on the Nemaha rift, other areas will be analyzed as well. The age of faults will be determined, particularly those with east-west orientation. Rocks not normally analyzed by oil companies (i.e., those younger than Pennsylvanian) will be examined.

If recent faults are found, seismic arrays will be installed over the fault zones using both permanent and temporary geophones, and seismic activity data will be collected. Microseismic data will also be collected and analyzed.

Finally, gravity, magnetic, and supporting geological data will be collected and considered as part of the overall analysis. This is a 5-year program; the bulk of the data analysis is to be done by the Tulsa Observatory, coordinated by Dr. Lusa.

State Energy Office. Mr. Hill was informed of the purpose of the visit to Oklahoma and that further work on geothermal energy in Oklahoma was planned. He suggested that the Federal Energy Administration be contacted to obtain the results of its study with the Department of Agriculture on agricultural uses of energy in Oklahoma.

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OPERATIONAL RESEARCH, GEOTHERMAL ENERGY §33
DEVELOPMENT AND UTILIZATION
Geothermal Program, Region 5 ZJ70CQO
Support: ERDA/DGE
C. A. Shipley
October-December 1976

SCENARIO DEVELOPMENT

Hot Springs National Park, AR, has been identified as the initial site for developing five basic scenarios for nonelectrical use of geothermal resources. Since the scenarios will vary in intensity of development, preliminary calculations were made for outlining the more modest ones. Information concerning existing plans for the use of geothermal energy by the National Park Service was obtained by C. A. Shipley in November 1976 during a visit to the Park. This information was previously unknown to APL (Ref. 1) but is similar in scope to the more modest scenarios postulated in the previous QR (Ref. 2).

DISCUSSION

The Hot Springs National Park was successful in converting the Administration Building heating system to the use of geothermal water instead of natural gas. This conversion has provided a practical basis for the Park heating for two of the eight bath houses along Bath House Row. As pointed out in Ref. 2, heating of the Administration Building by geothermal energy uses less than 0.4% of the water from the hot springs. An ample supply of water is available because only 11% is being used for the original balneological purposes. Since the Administration Building has some 5600 ft^2 of space above the basement that is now geothermally heated, extension of geothermal heating to the two additional bath houses (which contain approximately 22 000 and 18 000 ft^2, respectively, of above-basement space) would result in only a modest increase to less than 4% of the geothermal water available.

Thus the modest use of geothermal energy by the Hot Springs National Park can provide a realistic checkpoint for the engineering and the cost analysis required in the various APL scenarios. In addition to the engineering and financial analyses, the impact of the programs on the environment and the economic community must be considered. Also, restrictions imposed by legal and sociological considerations must be taken into account. The familiarity and experience of the Hot Springs National Park program can be helpful in the Laboratory's development of postulated scenarios for the Park area.

FUTURE PLANS

Further specification of the postulated scenarios by the Laboratory and a review of the implications of the more ambitious scenarios will be carried out with consideration being given to the plans and experience of the Hot Springs National Park.

The next scenario to be developed will be of one or more sites in western South Dakota, where a number of potential low-temperature geothermal sources exist with water temperatures (140 to 160°F) that are probably most appropriate for space heating and certain agricultural and industrial processes. The Hot Springs National Park scenario data will undoubtedly contribute to the space-heating aspects of the South Dakota scenario.

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ENERGY PRODUCTS §34
Exchangers for OTEC Systems ZH90BBP
Support: ERDA / SED
P. P. Pandolfini
October-December 1976

TEST AND ANALYSIS OF OTEC HEAT EXCHANGER DESIGN

In November 1976, an initial experimental program was completed in which ammonia-side heat-transfer coefficients were determined using an electrically heated tube to simulate a single pass of an OTEC (Ocean Thermal Energy Conversion) evaporator. The tube was 20 ft long, horizontal, and made of 3-in.-OD aluminum. Effects of flow rate, heat flux, and inlet quality (up to 20% vapor, by mass) were evaluated as well as effects of small changes in tube inclination on the degree of dryout at the top of the tube. The 29 tests covered mass flows of 1.0 to 2.8 lbm/s, heat fluxes of 1100 to 2300 Btu/h-ft^2 (provided by an electric tape winding), qualities up to 20% vapor (controlled by a steam-jacketed preheater), and tube declination angles, α, of +0.26 to -2.0° (positive is downward).

SUMMARY AND CONCLUSIONS

Accuracy was best in the 16 tests in the final run because of added instrumentation. Results of the 16 tests are in satisfactory agreement with the Chaddock-Brunemann correlation for two-phase-flow heat transfer. This correlation relates the two-phase coefficients to the all-liquid-flow coefficient through a function of the boiling number (Bo) and the Martinelli parameter. The ratios of the overall averages (all stations and all four circumferential positions within the tube) of the two-phase heat-transfer coefficients, $h_{1(4)}$, to that of the liquid heat-transfer coefficients, h_L, (computed from the Dittus-Boelter equation) are plotted in Fig. 1 for the last series of tests. The Chaddock-Brunemann correlating equation (Ref. 1) is shown by the curves in the figure for two values of Bo × 10^4 (0.090 and 0.285) that bracket the values for the tests. The experimental results are in satisfactory agreement with these correlating curves. For the low qualities tested, dryout occurred at the top of the tube over its entire length at α = +0.26°, over the first two-fifths for α = -0.21°, and in some cases in the first fifth at α = -2°. To observe the overall statistical effect of poor heat transfer at the top of the tube (which is the consequence of dryout), the ratio of $h_{1(4)}$ to the average for the lower three-fourths of the tube, $h_{1(3)}$, is plotted in Fig. 2. It is seen that the points from run 6 (α = -2.0°) fall near a value of 0.91, those from runs 4 and 5 (α = -0.21°) fall near 0.84, and those from runs 2 and 3 fall almost perfectly at 0.75, clearly indicating a strong dryout effect for runs 2 and 3 when the tube was declining at α = +0.26°. It is judged that a small upward tilt in the flow direction (say α = -0.5°) in the first ten passes or so covering this quality range would suffice to produce results essentially equivalent to the prior predictions for this heat exchanger concept.

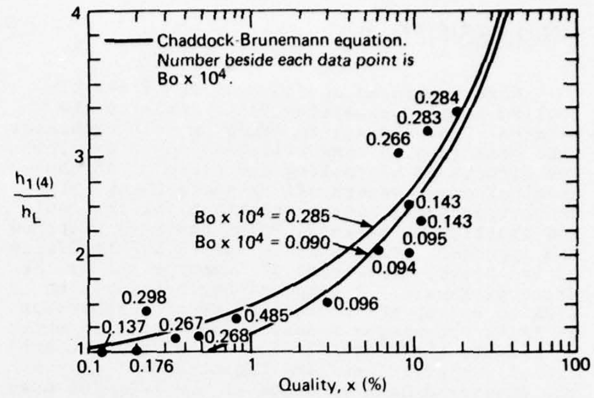

Fig. 1 *Comparison of Measured Heat-Transfer Coefficients to Chaddock – Brunemann Correlation. (76-4/49)*

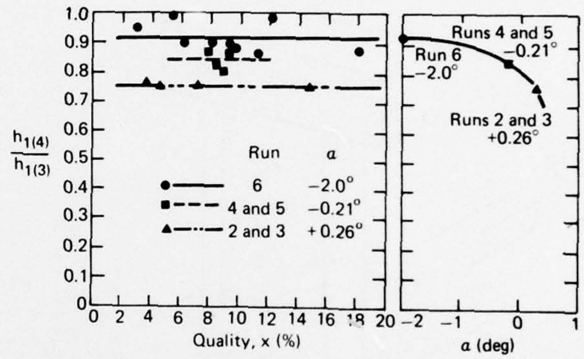

Fig. 2 **Effect of Dryout at the Top of the Tube. The ratio of overall tube average heat-transfer coefficient to the average of the lower three-quarters of the tube is shown as functions of quality, x, and declination angle (positive is downward). (76-4/50)**

FUTURE PLANS

The results and conclusions from the test program are being reported to the Energy Research and Development Administration (Solar Energy Division) with the following recommendations (Ref. 2):

1. The Phase II test program with full-scale models of evaporator and condenser sections in a closed loop ("core tests" in ERDA parlance) should be pursued on a high priority basis.
2. The stratification flow phenomenon should be characterized by more detailed testing at design and off-design operating conditions. This can be done with the existing internal-flow test apparatus but will require replacing some instrumentation: All surface temperature sensors should be replaced with peened-in thermocouples.
3. The occurrence of nucleation in the subcooled flow should be characterized in more detail, especially with respect to the location of inception. This will require additional instrumentation at points between the four stations used in the present series of tests

Work continued on fabrication of the biofouling testing apparatus that simulates the external flow through an APL/OTEC heat exchanger tube bank (Fig. 3) and will be used to examine the effects of biofouling and cleaning in the tropical ocean waters off Ke-ahole Point, HI. An environmental impact statement for the testing facility at Ke-ahole Point has been prepared and approved. This work is funded by the Office of Sea Grant, Department of Commerce, and by the State of Hawaii. A proposal has been made to ERDA to set up the biofouling testing apparatus at APL's Propulsion Research Laboratory in order to measure the external flow (water side) heat-transfer coefficients and the pressure loss in the staggered bank of tubes of the APL/OTEC heat exchanger.

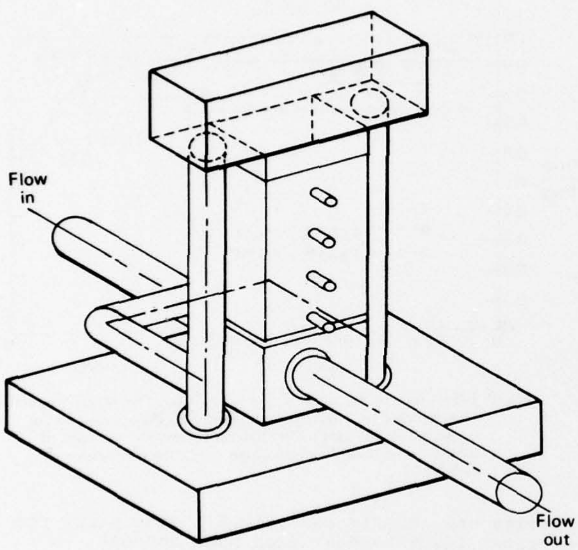

Fig. 3 Biofouling Test Apparatus. (76-4/51)

Work also continued on the Commercial Development Study for OTEC under sponsorship of the U.S. Maritime Administration. A report on this work is expected during the first quarter of 1977. The desired minimum requirements for a tropical ocean OTEC pilot plant and test program were developed. They include:

1. The heat engine — 20 identical units;
2. The platform — one central structure plus 40 identical evaporator and condenser heat exchanger cells;
3. The cold water pipe — one 60-ft-dia pipe;
4. The water pumps — 19 identical cold-water pumps, 20 identical warm-water pumps;
5. The control system — 20 local control systems plus one supervisory system;
6. The electrical generators — 4 identical units available as commercial items in a range of sizes;
7. The heat exchanger cleaning system;
8. The electrolysis system — 20 identical units;
9. Air liquefaction and N_2 separation — one plant (optional) available as a commercial item; and
10. Ammonia plant — one plant (optional) available commercially.

Preliminary cost estimates for this minimum pilot plant are from $29.5 to $37.5 million with an approximate construction time of 24 months.

A proposal was prepared to use the APL research vessel Beayondan for tropical ocean onsite OTEC data gathering.

DISCUSSION

Development of the APL concept for OTEC plant-ships began in 1973. The basic idea was first proposed by d'Arsonval in 1881, and an open-cycle approach was demonstrated by Claude in 1930 (Ref. 3). Modern interest, spurred by the energy crisis and supported by the similarity of the required closed-cycle technology to that of the refrigeration and air-conditioning industries, has been reviewed (e.g., in Ref. 4). The status of projects initiated by the National Science Foundation and transferred to ERDA in 1975 was reviewed in a workshop run by APL for ERDA (Ref. 5). That workshop featured studies conducted by industrial teams headed by TRW and Lockheed. The latter studies strongly supported the technical feasibility but indicated that the costs would be high due to study constraints and the selection of titanium heat exchangers, which represented 50 to 58% of the costs. The aforementioned features of the APL concept, described in detail in Ref. 6, were developed with the specific goal of acceptable cost.

Since the APL concept for the heat exchangers is novel, experimental demonstrations being supported by ERDA are required. Initial tests of two-phase-flow heat-transfer coefficients for ammonia inside a 3-in.-dia electrically heated aluminum tube were completed in the last quarter, and a report is being issued to ERDA (Ref. 2). The apparatus to be used for measuring external (water side) heat-transfer coefficients, the pressure drop across the bank of staggered tubes, and the rates and effects of biofouling in the heat exchanger has been fabricated. Testing will begin during the next quarter; the first two parts of the investigation are proposed to be conducted at the Propulsion Research Laboratory. The third part will be done at Ke-ahole Point in a joint effort with the University of Hawaii. The testing site has been prepared by the University of Hawaii and will be ready after the completion of tests at APL. Full-scale tests of a closed-loop model that contains the evaporator and condenser (core tests) are being planned; testing is expected to be at ERDA's Argonne National Laboratory.

Further investigation of commercialization prospects is also continuing under support of the U.S. Maritime Administration. The initial investigation for the Maritime Administration (Ref. 6) received substantial contributed support by the Sun Shipbuilding and Dry Dock Company and by Avondale Shipyards on ship design. Subcontracted support was obtained from Hydronautics, Inc. on platform motions and other marine aspects; from Woods Hole Oceanographic Institution on site selection and design criteria; from aluminum plant engineering consultants; and from the law firm of LeBoeuf, Lamb, Leiby, and MacRae on international legal considerations. Many companies provided informa-

(continued)

tion on OTEC and product equipment. The potential for successful, near-term commercialization of the vast OTEC resource in tropical oceans appears to warrant substantial early funding and a national priority by government and strong financial support by industry.

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ENERGY CONSERVATION STUDIES §35
Community Annual Storage Energy System
F9K0CPE/S2P
Support: ERDA-ANL Contract 31-109-38-3627
W. R. Powell October 1976

COMMUNITY ANNUAL STORAGE ENERGY SYSTEM (CASES)

A project is under way to evaluate the Community Annual Storage Energy System (CASES). CASES is a novel heating and cooling system that appears both more economical and more efficient than methods currently being used (Refs. 1 through 3). The problem of space heating and cooling with little energy consumption has a simple theoretical solution. Surplus heat collected in summer can be stored and used in winter; ice formed in winter can be used for subsequent summer cooling. However, it is prohibitively expensive to store enough "free" heat in warm water to meet heating season needs. But if an ice-forming heat pump is used to extract additional heat from the stored water, then the storage volume required is no more than one-tenth the original, and the cost appears reasonable (Ref. 4).

Ordinary heat pumps waste the cooling produced concurrently with heating, but in CASES the ice formed while heating is saved for summer cooling. Thus with annual storage, little electric power is required for summer cooling. Significant capital savings for utility companies with peak summer demands may be possible even if the utility company provides all of the capital required by CASES.

DISCUSSION

Recent trends in residential heating and cooling have not helped the cause of energy conservation. In 1974, only 12% of existing residences were electrically heated, but 53% of all new residences were built with electric heat (Ref. 5). Only 8% of these new "all-electric" homes used a heat pump (Ref. 6, p. V-66). Electric heating units require at least 50% more primary energy than fossil-fired furnaces. Thus, in spite of greater emphasis on better insulation, little reduction in the primary energy required to heat new residences has been achieved. Ultimately, the trend to nuclear power plants can divert fossil fuels into uses more beneficial than combustion, but the rapid escalation of the cost of these plants and other factors have significantly delayed the day when a net savings of fossil fuel will result from the conversion to electric heat.

The electric utility industry has promoted electric heat in an attempt to balance seasonal loads. The rapid growth of air conditioning has caused seasonal load factors to decline from 65.3% in 1967 to 61.2% in 1974 (Ref. 7). The Federal Energy Administration (FEA) estimates that load factors can be improved to 69% by 1985 by load management and control (Ref. 8). Installation of residential load control devices, "time-of-day" meters, and thermal storage devices to improve load factors is expensive. Generally it is the heating, cooling, or hot-water loads that can be diurnally managed by these devices. CASES can provide this diurnal thermal-load management from one central point (i.e., without need for expensive residential load management devices). Furthermore, CASES improves seasonal load factors by reducing summer cooling loads rather than by increasing electric heat demand to keep up with uncontrolled growth in air conditioning demand. Thus, with CASES the seasonal load factor is improved and the peak load generation capacity required is reduced; i.e., not only is the generation equipment better used with CASES but also the total capital required for new plants can be reduced if summer air conditioning is accomplished by melting ice formed in winter. It is not yet clear if the utility investment capital that CASES can save by avoiding residential load management devices, by better load factors, and by reduced expansion requirements is fully adequate to cover the capital cost of CASES. However, initial estimates (Ref. 1) indicate that the net effect of a CASES community is to reduce the total capital requirements compared to an all-electric community.

In an era of energy shortage, initial cost (capital) considerations cannot be permitted to determine the type of heating and cooling equipment installed. Baseboard electric heaters and room air conditioners are the cheapest and least efficient systems available for heating and cooling. Their initial cost is $1000 to $1200 less than a conventional heat-pump system (Ref. 6, p. V-63). Unfortunately, even life-cycle-cost arguments cannot overcome the economic advantage of this low initial cost. In all nine cities studied for ERDA, baseboard electric heat and window air conditioners had lower annual owning and operating cost than conventional heat pumps (Ref. 6, p. V-65). Nonetheless, since heat pumps can heat as efficiently as oil- and gas-fired systems and also permit coal and nuclear energy to be substituted for these scarce resources, it is imperative that society finds ways to reverse the present trend toward resistive electric heat.

Since CASES does not waste the out-of-season cooling output from its heat pumps, it is at least twice as efficient as a conventional heat pump. If part of both the cooling and heating required by the community is obtained energy-free (see Ref. 3), then CASES can be several times more efficient than conventional heat pumps. A 75% reduction in fuel required for CASES as compared to a conventional heat pump system will have significant impact on the owning and operating cost. CASES may be the least expensive system to own and operate as well as the most efficient system. If this is true and since no new technology is required, why is CASES not in existence today? Part of the answer relates to the potentially high start-up cost for CASES.

CASES must be designed for modular growth to avoid excessive capital cost in the start-up years. It would appear that a modular growth concept is in conflict with the concept of a single large (economical) community energy storage facility, but this is only partially true. (Storage cost per unit volume decreases rapidly as volume increases.) Initially CASES might have no thermal storage other than the thermal inertia of the large distribution mains that operate near ground temperature as either a heat source or sink for local water-source heat pumps (chillers). As the thermal load of the community develops, capital would be invested in short-term storage facilities and central heat pumps (ice machines) so that more heating capacity and prolonged cooling from storage recharged at off-peak electric rates would be available. Ultimately, the capital cost for a large annual-storage ice facility would become less than the cost of operating heat pumps both summer and winter; i.e., it would pay to save ice coproduced in the heating mode and avoid the energy cost of running heat pumps in summer for cooling. The short-term storage facilities previously acquired would be used to buffer the ice plant so that economical use of ice-machine capacity is possible. Some southern sites where seasonal cooling requirements are much larger than can be met through ice that is produced incidental to heating or collected "free" on below-freezing days may never reach the stage where annual storage is economically justified. The southern limit of the CASES concept is identical with the concept of communal heat pumps and short-term storage for off-peak air conditioning. Likewise in the northern limits of CASES, it must be combined with solar or air heat collection to melt ice on mild winter days so that the 144 Btu/lb of water can be extracted many times.

Market penetration of CASES after inital demonstration projects should be rapid. Unlike other energy-saving measures such as better insulation, storm windows, etc., CASES reduces the building cost below that of a building equipped with a furnace and central air conditioning. The building owner does not buy any heating and cooling units but instead subscribes to a thermal utility.

The large-scale CASES equipment is more economical, more efficient, and less costly to maintain properly than small privately owned heating and cooling equipment. Private air conditioners often become so inefficient due to lack of maintenance that they cannot supply the cooling desired even with continuous power consumption. The heat pumps in CASES need not revert to electric resistance heating on cold days and are thus more efficient even than properly maintained conventional (air-source) heat pumps. Furthermore, because of diversity of demand and the thermal storage of CASES, the total installed capacity for CASES can be less than for a community with conventional independent heating and cooling equipment. Thus energy, equipment, and maintenance costs are less in CASES.

The distribution system cost is less than the sewer and water line cost for a community. The pipe employed for main-line distribution in CASES is uninsulated pipe much like sewer pipe. Trenches need not be as deep as sewer lines, as flow is pumped in CASES. In CASES, the water is only a vector for heat and is not consumed. No sewer plant cost is associated with the sewer-line pipe of CASES. Consequently, the capital cost to the community for a CASES distribution system is small compared to present cost for sewer and water lines. It appears that the extra capital cost of distributing thermal water instead of gas and/or oil in the community will be less than the capital saved at the power plant to meet increased summer cooling loads present without CASES plus the capital saved in the community by the purchase of large economical equipment instead of individual space conditioning plants and load control or storage devices. The cost of annual ice-storage facilities for CASES is incurred only when it is found to be cost effective compared to continued operation in the off-peak air conditioning mode.

FUTURE PLANS

The only technical problems in the CASES concept are system problems; all of the equipment required has been in commercial service for many years.

In order to evaluate the seasonal performance of the CASES concept, an interactive model will be constructed. Various design changes and operational strategies will be tested with at least a full year of weather data. Systems control and the effect of equipment or sensor failure must also be studied. These activities were not possible during the last two months of this quarter because of delay in the issuance of the contract extension.

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ENERGY CONSERVATION STUDIES §36
Ammonia Absorption Cycle X85ZS3E
Support: Task X/N00017-72-C-4401
R. J. Taylor
October-December 1976

USE OF THE AMMONIA ABSORPTION CYCLE TO HEAT AND COOL BUILDINGS

One possible system for using low-grade energy for heating and cooling is the ammonia absorption cycle. This cycle makes possible the use of low-grade heat from low-temperature geothermal sources and waste heat from power plants. The ammonia absorption cycle can use temperatures as low as 100°F to distill or separate the ammonia from the ammonia-water solutions. The energy of distillation drives the cycle and allows the user to heat or cool with the system. Also, the ammonia can be piped hundreds of miles, using only a fraction of the energy ultimately delivered. Thus this system holds great promise for providing inexpensive energy for heating and cooling homes.

DISCUSSION

A generalized diagram of the ammonia system is shown in Fig. 1. The ammonia is separated by distillation from the ammonia-water solution via the input of thermal energy from the geothermal source or waste heat from a power plant. The thermal energy is thus stored chemically in the separated ammonia. The ammonia is piped to the user who extracts the heat by adding water. Ammonia and water yield a heat of mixing similar to the heat of mixing generated by adding sulfuric acid to water. The user also has the option of cooling with the ammonia via the absorption air conditioning principle. Because water readily absorbs ammonia vapor, liquid ammonia in vapor contact with water will rapidly evaporate and provide cooling. At 1 atm of pressure, ammonia boils at -28°F, thus providing excellent cooling for many requirements of the home and the industrial world. The ammonia-water solution generated by heating and cooling is then piped back to the thermal source, and the ammonia is redistilled and recycled.

The main advantages of this system over conventional geothermal heating systems are:

1. Cooling as well as heating is provided.
2. The power required for distribution and the energy lost in distribution are significantly smaller than for conventional district heating systems.
3. The user can also store the ammonia for periods of greater demand. Thus, the system can distill the ammonia at a constant rate for maximum efficiency; at the same time the user can meet a rapidly changing load without adversely affecting the system performance. Community storage facilities could also be used for collecting and storing the ammonia when air conditioning or heating is not needed. This could provide heating or cooling for a greater number of buildings.

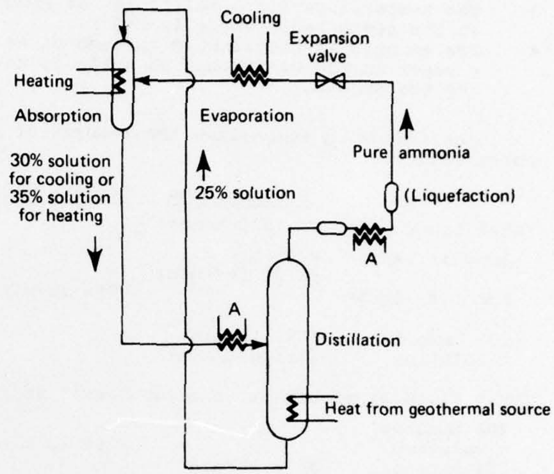

Fig. 1 Generalized Diagram of the Ammonia Absorption Cycle. (76-4/45)

4. This system is not only applicable to geothermal usage, but it makes the use of waste heat from power plants more feasible. One reason use of waste heat has been slow to develop is that during the summer the requirements for disposal of waste heat are greatest while the user's need for heat is least. For example, the cooling towers needed to expel the waste heat into the atmosphere during the summer are generally four times the size needed during the winter, when waste heat could be more readily used. Thus, to use waste heat from power plants economically there must be a good method to use or store the thermal energy during the summer. The system described here does both. It can use waste heat for air conditioning in the summer and at the same time provide a chemical means of storing the thermal energy for heating in the winter.

A point design for a system to supply the heating and cooling for 1000 homes was accomplished. The point design was not optimized; its main function was to illustrate the system. The distillation temperature was limited to 140°F. The fact that the system works reasonably well even at this low temperature speaks highly for its potential.

The assumptions and parameters that form the basis of this point design are:

1. Each home requires 4×10^5 Btu/day (277.8 Btu/min) of heating at a temperature of 140°F during the winter.
2. Each home requires 2×10^5 Btu/day (138.9 Btu/min) of cooling at a temperature of 30°F during the summer.

3. The temperature for distillation of ammonia at the geothermal source is 140°F.
4. The ammonia is distributed through pipes as a vapor in the winter and as a liquid during the summer.

The following summarizes the results of the point design:

	Heating Mode	Cooling Mode
Total fluid piped to 1000 homes:		
Ammonia vapor	478 lb/min (2120 ft^3/min)	
Ammonia liquid		284 lb/min
25% Ammonia solution	3097 lb/min (410 gal/min)	
Total fluid piped back to the geothermal source:		
30% Ammonia solution		4260 lb/min
35% Ammonia solution	3575 lb/min (490 gal/min)	

The external work supplied for compression of the ammonia vapor in the heating mode is 9.2% of the thermal energy output. For the cooling mode, the required external work for compression and liquefaction of the ammonia vapor is 23% of the thermal energy extracted for cooling by the system. If the distillation temperature were raised to 240°F, no external work would be required to compress the ammonia vapor in either the cooling or the heating mode, and the amount of total ammonia and 35% solution needed for the heating mode would be reduced by 54%.

The power required for distribution of the fluids is critically dependent upon pipe diameter. Pumping power, P_p, is related to the pipe diameter, D, by the following proportion:

$$P_p \propto D^{-5} .$$

For the following pipe sizes — 25% solution, 4 in.; 35% solution, 6 in.; and ammonia vapor, 12 in. — the pumping power to pump each fluid 10 mi is 13% of the thermal energy delivered in the heating mode. In order to pipe the same fluid 100 mi with the same percent of pumping power required, the pipe diameters are 25% solution, 6.3 in.; 35% solution, 9.5 in.; and ammonia vapor, 19 in.

One very attractive feature of the considered design is that no outside heat exchanger is needed during the winter or summer. For example, the main capital expense (at the home) of a home air conditioner is the outside heat exchanger and compressor. The outside heat exchanger makes the typical absorption air conditioning more expensive than the electrical-mechanical compressor. The waste-heat temperature from the absorption machine must be kept low so that the pressure required for absorption is sufficiently low for easy evaporation of the ammonia. The low-temperature waste heat (to be dissipated into the air) requires a large and costly heat exchanger. The waste heat in the point design considered is piped out of the house and back to the geothermal source in the mixed ammonia-water solution. Thus, the capital cost (at the home) of the ammonia absorption heating and cooling unit should be substantially lower than the cost of an equivalent furnace and air conditioner.

CONCLUSIONS

The non-optimized point design considered works reasonably well even for the rather low distillation temperature of 140°F. Elimination of the outside heat exchanger should make the proposed heating and cooling absorption units significantly cheaper than equivalent conventional heating and cooling systems. Thus the system holds great promise for providing an inexpensive energy distribution system for heating and cooling buildings.

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C. Feldman, H. K. Charles, Jr., F. G. Satkiewicz, and N. A. Blum October-December 1976

VACUUM-DEPOSITED POLYCRYSTALLINE SILICON SOLAR CELLS

Vacuum deposition is a well-known and accepted method for producing large-area layers of metals, dielectrics, and some semiconductors such as selenium and cadmium sulfide. In the past, difficulties in the vacuum deposition of semiconducting grade silicon (and germanium) have led researchers to avoid these materials for practical applications. This report describes recent work on vacuum-deposited polycrystalline silicon films. It indicates that thick, high-purity, polycrystalline films with a larger grain size can be deposited, and thus devices may be fabricated from silicon films. Production by vacuum deposition of large-area solar cells at low cost is a realistic goal.

Articles have been published in the literature on: (a) vacuum deposition and secondary ion mass spectrometry (SIMS) analysis leading to very pure silicon films (Ref. 1), (b) the crystallization kinetics of amorphous silicon films (Ref. 2), (c) the formation of p-n junctions and devices on fused silica substrates by standard diffusion techniques (Ref. 3), and (d) the formation of diodes with some photovoltaic response in thin samples that were deposited in amorphous form on sapphire and subsequently crystallized (Ref. 4). In this report, diodes will be described that were formed in high-purity polycrystalline silicon films up to 33 μm thick. The layers were deposited on sapphire substrates in order to avoid complications of mismatched expansion coefficients and impurities introduced through the substrates. Planar p-n junctions were formed by a conventional integrated-circuit double-diffusion process.

SUMMARY

Experimental solar cells were fabricated from vacuum-deposited polycrystalline silicon films using conventional integrated-circuit (IC) processing techniques. Solar cell efficiencies of approximately 2% (AM2) were obtained from small devices with no attempt to optimize the electrode configuration and without an antireflection coating. Directions for improvement in processing and structure are indicated that could lead to the development of low-cost, large-area, photovoltaic devices suitable for terrestrial conversion of solar energy.

DISCUSSION

Silicon films were vacuum deposited from a molybdenum-lined, water-cooled, nickel crucible that was heated by means of an electron gun; the beam power was varied from 1 to 2 kW to achieve various deposition rates. The source-to-substrate distance was kept relatively short (9 cm) in order to produce thick samples. Six substrates (2.54 × 0.85 cm) were coated during each deposition cycle. Precautions necessary for maintaining sample purity have been described elsewhere (Ref. 3).

Deposition parameters are given in Table 1. Predeposition pressures were approximately 5×10^{-9} Torr. Film thickness was determined from measurements of the infrared transmission interference fringes.

Table 1
Deposition and Film Parameters

Sample	Si 130	Si 147	Si 149	Si 155
Pressure (Torr)	1.3×10^{-6}	2×10^{-7}	7×10^{-7}	5×10^{-7}
Substrate temp. (°C)	500	640	800	980
Thickness (μm)	13.8	5.0	8.5	33.0
Deposit rate (nm/min)	490	14	23.6	91.7
Grain dia (μm)	0.2	0.9	1.5	5.0

Films were examined by scanning electron microscopy (SEM) immediately after deposition and at various stages in the subsequent processing. There appeared to be little observable change in surface grain appearance that could be attributed to processing. Grain diameters were observed to increase with an increase in substrate temperature (Table 1).

p-n Junction Formation. Double-diffused p-n junction diodes were formed in polycrystalline films by a 15-step, three-level, photolithographic, double-diffusion process. These procedures are based on industrial practice for single-crystal processing and were developed from our previous experience with extremely thin, small-grained films on fused silica substrates (Ref. 1). Single-crystal wafers were processed along with the polycrystalline samples.

All samples were processed according to identical schedules in order to allow comparisons between film specimens. Oxidations and diffusions were performed at 975°C. Boron (from diborane) deposition time was 5.5 min followed by a 2-h oxidation process and a 20-h dry nitrogen drive-in. Phosphorus (from phosphine) deposition time was 6.5 min with a subsequent 2-h oxidation step.

SIMS Analysis of Diffusions. The secondary ion mass spectrometric analysis of Si thin films included determining impurity content and dopant profiles. The impurity content of the films and the sputter ion source mass spectrometer used for the analysis have been described previously (Ref. 1). The extraction area was large enough to ensure results representative of a film.

Typical SIMS profiles are shown in Fig. 1 for films Si 147B and Si 149B and their corresponding single-crystal monitor. In these samples, the oxide layers had been removed so that distributions of dopants were obtained in the silicon alone. Data collected for other films with the oxide retained will be useful in testing models for diffusion in oxidizing ambients. Profiles such as those shown in Fig. 1 have demonstrated that control of doping levels in films may be achieved in the same manner as in single crystals.

Photovoltaic Response. Photovoltaic response I-V curves were obtained by illuminating the sample with a 150-W xenon lamp filtered by a 4.0-cm water path and a glass UV filter to produce an irradiance of approximately 0.075 W/cm^2. As can be seen in Fig. 2, the photovoltaic response increases considerably with an increase in grain size.

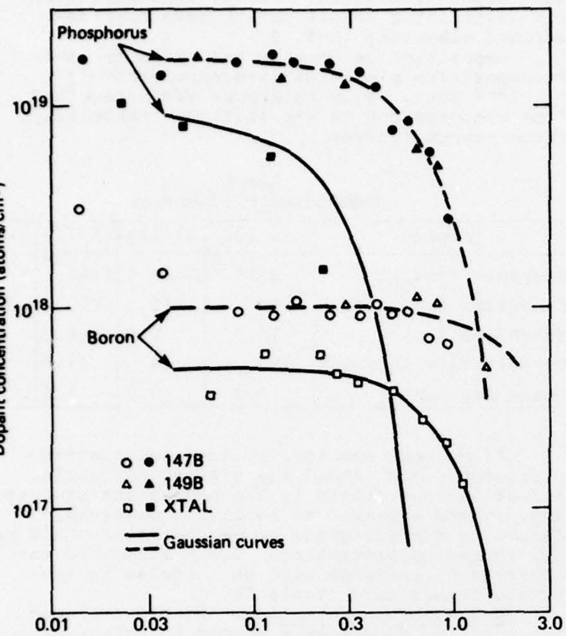

Fig. 1 SIMS Dopant Concentration Profiles for Polycrystalline Films (Si 147B and Si 149B) and a Single-Crystal Monitor. Curves represent a gaussian fit. (76-4/46)

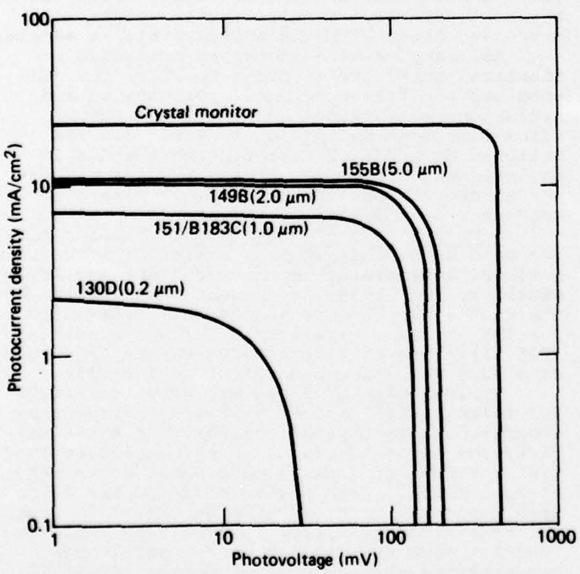

Fig. 2 Illustrated I-V Characteristics for Polycrystalline Films with Various Grain Diameters and a Crystal Monitor. (76-4/47)

Measurements of quantum efficiency were made using a Bausch and Lomb high-intensity grating monochromator with a tungsten (quartz iodine) light source. The spectral irradiance at the sample position was measured by a pyroelectric radiometer having an accuracy of ±10%. Relative quantum efficiency curves for a conventional solar cell (Spectrolab 2 × 2 cm space-qualified cell) and for a thin-film cell (Si 155B) are shown in Fig. 3. The spectral quantum efficiency is defined as

$$\eta_a(\lambda) = \frac{I_{sc}(\lambda)\ \phi(\lambda)}{P(\lambda)\ A} ,$$

where $I_{sc}(\lambda)$, $\phi(\lambda)$, and $P(\lambda)$ are the photovoltaic short-circuit current, the photon energy, and the irradiance on the sample, respectively, all at the wavelength λ, which is the center of the monochromator passband; and A is the exposed active sample area. In Fig. 3 the curves were normalized to the highest efficiency found in the commercial solar cell. Spectral quantum efficiencies of both the film and companion single-crystal monitor (not shown) are skewed toward the short wavelength end of the visible spectrum. The origin of this skewness is under investigation. In the film it may be due to nonuniformity in structure resulting in a smaller effective thickness, while in the crystal monitor it may be due to the presence of a deep back junction brought about through the use of n-type wafers.

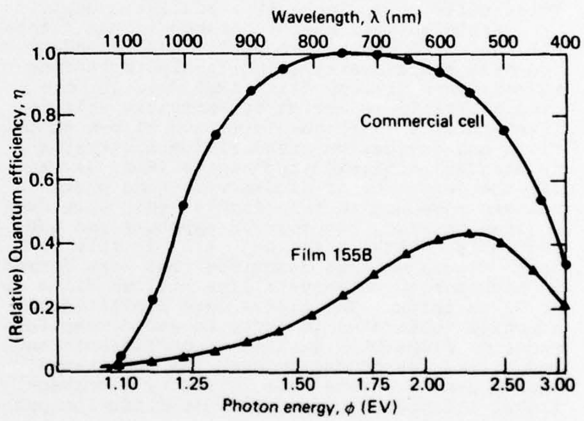

Fig. 3 Normalized Spectral Response Curves for a Commercial Solar Cell and a Polycrystalline Silicon Film (Si 155B). (76-4/48)

CONCLUSIONS

Investigations toward forming low-cost polycrystalline silicon solar cells by vacuum deposition have been carried out. It has been demonstrated that high-purity, thick films with large ratios of grain size to thickness could be deposited. p-n junctions could be formed in the samples by both unilateral and bilateral double diffusions. The devices showed promising efficiency (1 to 2%) as solar cells. Optimization of geometry and deposition conditions would be expected to increase the efficiency. Nondiffusion techniques of p-n junction formation such as the simultaneous deposition of silicon and dopant warrant exploration. In addition, Schottky-type barriers on the silicon film surface may prove interesting. The important and

(continued)

difficult task of finding a suitable, low-cost substrate must now be undertaken, and the use of composite structures may aid in the selection.

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